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GEOSTATIONARY ORBITAL CROWDING:

AN ANALYSIS OF PROBLEMS AND SOLUTIONS

by

ROBERT MURRELL WILKISON JR.

B S., Virginia Military Institute, 1984

A thesis submitted to the

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Geostationary Orbital Crowding: An Analysis of Problems and Solutions
Thesis directed by Professor Joseph N. Pelton

Geostationary orbital crowding is currently a pressing international issue. At the nucleus of the problem is the disagreement between undeveloped and developed nations as to whether geostationary equity or efficiency should be the emphasis of international orbital slot and frequency allocations. The primary desire of less developed nations is an assurance that fundamental satellite resources will be available for their use when they are technically and economically able to launch satellites. They argue that this can only be realized if the international community sets aside resources for their exclusive use, to be usable when their needs and abilities so dictate.

The developed countries feel that such a plan would result in an inefficient utilization of orbital resources. They also believe that by the time these undeveloped nations are able to launch communications satellites, technology will have made added resources available for their use. Thus, the question remains, should the international regulatory community loosely

influence this "limited natural resource," permitting technology to dictate future availability or do they closely regulate it and absolutely guarantee that all nations will have at least limited future use.

The best possible plan will be one that uses a composite of all practical options. All technical solutions must be incorporated as they become viable, while regulatory alternatives should be implemented as needed, to ensure that every nation has access to space communications resources when their situation dictates. Excess orbital resources may be marketed to further the development of telecommunications in the developing world. Various methods for ensuring both efficient and equitable future access to space communications resources are detailed in this thesis.

DEDICATION

I wish to dedicate this thesis to my family, who have supported me through this endless process of researching and writing this paper. My wife, Lynn, I thank you for caring for our house and children (with little or no help from me), in the loving and caring way that you approach every aspect of your life. I also thank you for being understanding of the lengthy hours that I have spent preparing this thesis and the many requests of yours that have, consequently, gone unspoken and/or unfulfilled. Well dear, I'm yours so start making those requests again. My other special girls, Brittany and Spencer, I thank you for being understanding of the many times that Daddy has had to say "I'm sorry, Daddy can't play with you right now." To you I also say, "I'm yours again, so lets play." And finally, to my unborn child (due in September), I say, "You do not know how lucky you are to be born after all of this is over."

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CHAPTER I

INTRODUCTION

This chapter explains the organization of the thesis and the composition of each chapter. It also includes a review of the research procedures, which led to the writing of this paper. Included in this will be a presentation of the most relevant sources, for use by those who may wish to do further research on this subject, an explanation of how this paper was written and researched, and a synopsis of how it is different from past works on GSO crowding.

Thesis Preview

Generally, this thesis will address the issue of geostationary orbital crowding and tender possible solutions for resolving this important international problem. Presentation of the material will be given in three parts. First, a background of communication and geostationary satellite technology and regulation will be given. Next, the possible technical, market, and regulatory solutions will be presented. Finally, the thesis will be concluded with an overview of the

major points and some opinions on how these possible solutions might be combined into an overall plan for equitable and efficient use of orbital resources and geostationary satellite communications. Important to understand here is that equity and efficiency are not mutually exclusive and that the goal of a final plan will be to adopt the best features from all options.

Like most background chapters, the intent of Chapter II is not to address all there is to know about communications satellites and orbits. Such an effort would take several volumes to present and would leave most readers thoroughly overwhelmed by its conclusion. The intent here is to present as much information as possible in a concise manner, so that readers who are not technically inclined will have an understanding of the semi-technical points to be covered in later chapters. Those with technical backgrounds may still wish to skim this chapter as kind of a refresher of rarely used information.

The purpose of Chapter III is to familiarize the reader with the important regulatory players and to give a brief history of the satellite regulatory process. Understanding decisions is much easier if there is a knowledge of the people and organizations who are making them. Knowing their motives, makes it

much easier to convince them that change is required. In addition, to make decisions concerning the future would be difficult without some concern for the past. Once again, those readers that are familiar with the regulatory process, can either read this chapter as a refresher or skip on to Chapter IV.

Chapter IV is where the fun begins. Covered here are the technical means of expanding the utility of the geostationary satellite orbit. It begins with basic solutions such as the use of alternative orbits and increased satellite utilization and progresses to the more futuristic options like spacecraft clusters and low Earth geostationary satellites. In between are some of the more practical expansion methods that can be implemented presently. These include advanced antenna designs, satellite coordination, and advanced communications techniques. In the efficiency versus equity and technology versus policy debate, we find technology and efficiency in Chapter IV and policy and equity in Chapter V.

Thus, Chapter V continues with the fun, but instead of covering the efficiency point of view, it addresses the equity side. The purpose of satellite regulation is to ensure the equitable utilization of all space communications resources. This includes an

assurance that existing systems will be allowed to operate free from harmful interference as well as guaranteeing the right of all, (with legitimate needs and desires) to access available resources. Playing important roles in this practice are both domestic and international regulatory procedures. Addressed by this chapter are means to best use these methods in service of users and potential users to ensure that all are treated fairly. Also included will be methods for making the current regulatory process work better and some new ways to prioritize the allocation of satellite resources.

Also covered in Chapter V are market options for the distribution of orbit slots and frequencies. Some suggest that it would increase both the equity and efficiency of geostationary operations if space resources were allocated based on economic instead of political factors. Equity would increase because the marketing of resources would result in a reallocation of profits from current satellite users to those that are presently financially or technically unable to do so. Efficiency would also increase because as demand for orbital positions increased, by economic reason, so must supply. Basically, when prices are high the market will drive the availability of new resources

through technical and regulatory means. In addition, the market will force an efficient use of available resources. (e.g. The more something costs, the less the probability that it will get wasted.)

Chapter VI provides two functions. First, it serves to review the important points from the first five chapters. Second and most importantly, it acts as a consolidation point. Since there appears to be no single correct remedy generally agreed upon for solving the geostationary orbital crowding problem, and since experts have been trying to tackle this problem with only limited success for twenty plus years, no magic solutions are identified in this thesis, nevertheless there are still important conclusions and findings. Most important is the conclusion that any viable solution, to this problem, must combine the strong points from several types of solutions. To show how this might be accomplished, this thesis will summarize recommendation on how an efficient and equitable geostationary orbit can be created and maintained.

Research Review

When selecting the subject of geostationary orbital crowding, it appeared that it would be mostly

a strength forward research topic. This assumption was partly attributable to the initial analysis that this problem could easily be solved using technical options. It turned out as is often the case, that any single dimensional or absolute answer to such a complex problem is most likely wrong. Technology will certainly help to solve many of our satellite resource problems, but it is now clear that many other factors must be figured into any workable solution.

Initial research exhausted available and requested library sources. This literature search concentrated on the most recent information available (except for historical events). It was estimated that by using current technical journals, books, and magazines, a useful view of events through mid 1989 could be acquired. Information concerning the most current events, from mid 1989 up to the present, was accomplished by interviewing experts from various relevant areas. Between the University of Colorado libraries of Business, Government Publications, Law, and Engineering plus the University of Wyoming's library, literary research was very productive. This research uncovered nearly 200 candidate sources, 150 of which were actively utilized.

The interview process was not nearly as successful. An interview with Mr. Cheikh Tidiane Ndiongue, the Director of Communication for Senegal, gave me a good feeling for the developing world's view on the use of the geostationary satellite orbit. This experience was doubly interesting for me because I had never before used an interpreter. Valuable information was also obtained via an interview with Dr. Joseph N. Pelton, currently the Director of the interdisciplinary Telecommunications program at the University of Colorado. He successfully provided useful information on INTELSAT, satellite history, and the marketing of the island of Tonga's satellite resources. In addition, five other international experts on various aspects of this subject areas were queried by letter. Unfortunately, only one of them wrote me back and he informed me that the data, which I requested, was not publicly releasable. Thus, this interview and questioning process proved to at best produce only modest results. Unfortunately though, without the current technical data, the technical solutions chapter is perhaps nine months out of date.

Considering the fact that about 90 references were used to write this thesis, it is hard to select one or two sources as being most helpful. As far as

key reference books are concerned, three were used most often. First of these, found in the University of Colorado business library, is the 1988 Rita Lauria White and Harold M. White Jr. edition titled The Law and Regulation of International Space Communications. It provides a very extensive review of the satellite regulatory process and is additionally valuable for its nontechnical method of explaining the technical means for expanding the utility of the geostationary orbit. The other two useful sources were borrowed from the University of Wyoming library. The first, a 1988 Geoffreye Lewis text titled Communications Services Via Satellite was an excellent reference for technical satellite information. And finally, the best single source of regulatory and technical information on geostationary communications was the 1987 Donald Jansky and Michel Jeruchim book, titled Communication Satellites in the Geostationary Orbit.

Anyone who spends nearly a year researching and writing a thesis is inclined to hope that their effort will provide some unique results. This paper is different because it covers the market, technical, and regulatory alternatives for both efficient and equitable use of the geostationary orbit. Most other publications address one of these subjects in some

detail but then skim over or do not discuss the other two areas. So this thesis may not provide the most in-depth coverage of any one aspect of geostationary satellite crowding, but for someone that is looking for a fairly detailed interdisciplinary discussion of the entire realm of satellite communications from the geostationary orbit, this thesis will serve that them very well.

CHAPTER II

TECHNICAL BACKGROUND

What is a communications satellite? What is the geostationary orbit (GSO)? To understand this often complicated issue of geostationary orbital crowding, it is essential that, at a minimum, you have basic answers to these two questions. Starting at the most elementary level, an artificial satellite is a man-made object which has been placed in orbit around the Earth. Communications satellites are ones which can be used for the transmission of information from one point to at least one other point. Finally, the orbit most commonly used for communication is the geostationary orbit, or in laymen terms, the single orbit which allows the satellite to maintain a fixed position with respect to the Earth. The remainder of this chapter will be used to expounding on these two fundamental points.

Communication Satellites

Satellite communication in the late twentieth century has become commonplace. They serve many

functions and provide many benefits to the people of the world. For example, most television coverage travels by satellite, at times directly from space into the home. No longer is it a novelty to see that a live television program has been carried via satellite (in fact, it is rarer to see one carried by another means). The majority of inter-continental telephone and data communication is also transmitted by way of satellites. In certain countries of the world, such as Indonesia, domestic satellites are even required to provide the most basic telephone service. Satellites used in this manner tend to bring nations and people of nations closer together.

A unique benefit of satellites has appeared in the area of emergency preparedness and response. One example of this was the devastating earthquake which hit Mexico City in September of 1985. The then newly launched MORELOS satellite was able to provide reliable television transmission to the entire nation even though all terrestrial long distance lines out of the city were inoperable.[1] In addition, a single INTELSAT transmission link allowed communication with the devastated city to be maintained. Such satellite operations show how spacecraft communications can be

used to better the condition of mankind and represent options not available twenty years prior.

From a technical point of view, satellites can be thought of as sky-born active repeaters. They have the potential to receive and amplify thousands of telephone channels and several video channels simultaneously for transmission to different ground and satellite users. Modern satellites, however, are more than simple microwave repeaters. They can transmit signals to multiple users spread out over a large geographical area. Satellite transmission has become highly reliable with beams shaped to provide efficient and effective spectrum usage to a given geographical area. Much of this progress has been made possible because of advancements in the areas of launch vehicles, satellite design and construction, and electronic components.[2]

The following sections will cover in more depth the various ideas just presented, in an effort to familiarize readers with the important specifics of communication satellites.

Introduction

The people of the world can no longer act and exist in isolation. All people and all nations of the world are being drawn together by such things as

the world economy and depletion of world's ozone layer. Things that happen in one part of the world often have dramatic impacts on events in other parts of the world. Communication through satellite is yet one more way that the world is being made to appear smaller and thus is influencing our perspective of world events. World news is now transmitted daily around the world via satellites. As part of its everyday operation, television stations are expected to provide up to the minute coverage of national and international events. Such reporting of world events would be virtually impossible without satellites.[3]

In the relatively short period of time since the introduction of the first commercial s_ ellite, EARLY BIRD, in 1965, communication via satellites has evolved rapidly to become the dominant global and regional medium of communications. The satellite industry has grown in less than twenty-five years to its presen_ status of now handling most international telephone traffic, all international and almost all domestic long-distance television programming, and a rapidly growing proportion of new domestic voice and data channels.[4] This rapidly advancing technology has literally placed us all under a global microscope

but hopefully this will give us all a new perspective of the shared problems and goals of a world society.

Purpose. Basically, communication satellites are electronic communication packages placed in orbit around the Earth. Their prime objective is to aid communication transmission between points on or near the Earth's surface. Today, this information could correspond to voice, video, or digital data to name but a few.[5] Essentially, these satellite systems are transparent to and often mere extensions of the relay systems which have been developed for terrestrial communications. The only difference, in many cases, being that the receiver/transmitter, known as the transponder, is now located in space. Instead of using terrestrial links, a communication satellite uses radio or light waves to communication between earth stations or other satellites, often separated by great distances. Their flexibility allows them to make valuable contributions to world communication in spite of high costs.[6] However, such high costs often allow satellite communications to be economical only when it is an extension of a system which facilitates continuous use and allows costs to be spread among numerous users.

A satellite's inherent capabilities, have found them many uses in the communications community for the following reasons: 1. Satellites are not distance sensitive. Specifically, the cost to send messages over a satellite link is virtually the same for all ranges within its coverage area.[7] 2. They are inherently wideband devices. Multimegahertz are available in each transponder channel and it can be utilized between any points within the coverage area. Satellite links can also be reallocated in off peak traffic periods to accommodate additional traffic. 3. One satellite can reach every point on nearly 40% of the globe at the equator, though its operating area is often regulated to much less. 4. Satellites are not limited by natural and man-made boundaries like mountains, cities, deserts, and oceans. Thus, unified service is available to widely distributed areas and populations. 5. Satellites are capable of serving urban and rural locations with nearly equal efficiency. Terrestrial networks, on the other hand, have always favored more populated areas.[8] These advantages have allowed satellites to be beneficial to not only the developed world, as replacements for existing terrestrial systems, but also to previously

unserved markets in the underdeveloped areas of the world.

When it comes to sending information over great distances reliability is of utmost importance, particularly when it involves data transmission. This is one area where satellites have proven to be much better than previously used communication modes. Ninety percent is considered to be a good reliability rate for underwater cables, whereas more than ninety-nine percent reliability is often achieved by the use of telecommunication satellites. In addition, single hop satellite links may allow more timely connections than alternative switched network services. This is especially the situation with store and forward data networks that may require the traversing of domestic and international gateways. Television is also the beneficiary of these same satellite benefits.[9]

Brief history. The space age was ushered in with the Russian launch of SPUTNIK, in October 1957. It became the first non natural satellite to circle the Earth. Since that time thousands of objects have been placed into orbit around the Earth, the Moon and other planets. Objects have even been launched out of the solar system.

Satellite communications began with the U.S. experiments, SCORE (Signal Communicating by Orbiting Relay Equipment) and ECHO, in the late 1950's and early 1960's. SCORE, launched in 1958, was a store and forward satellite designed to demonstrate the feasibility of using satellites for communications. ECHO 1 & 2, launched in August 1960 and January 1964, were large metalized balloons, used to reflect radio waves. The first successful active communications satellite was the Bell System developed TELSTAR, put into orbit in July 1962. Being in low orbit, it was visible to ground stations for only about 25 minutes at a time.[10]

In 1962 Congress turned the satellite world upside down by passing the Communications Satellite Act. It established COMSAT (Communications Satellite Corporation) and barred Bell System from any farther participation in satellite communications.[11] Two years later, on 20 August 1964, the International Telecommunications Satellite Consortium (INTELSAT), was formed with a charter to create a single global communications satellite system. With COMSAT as its first manager, INTELSAT had participating country's pledge to prohibit competing international systems.[12]

In the early years of the space age, launch capabilities were very limited and thus, the first geostationary satellites were small and rudimentary. The first communication satellite to be successfully maintained and operated in geostationary orbit was the joint Department of Defense-National Aeronautics and Space Administration (NASA) sponsored SYNCOM II, in July 1963. Though its final orbit was slightly off geostationary, SYNCOM II proved that such space communications operations were possible. The SYNCOM satellites were built by the Hughes Aircraft Company, under the leadership of Dr. Harold Rosen. SYNCOM I, launched in February of 1963, was destroyed when its apogee kick motor exploded. SYNCOM III was launched in August 1964 and achieved a precise geostationary orbit where it was operated. This program's success convinced COMSAT to use the geostationary orbit for its planned INTELSAT global communications system. They contracted with Hughes to build the EARLY BIRD satellite, later designated INTELSAT I.[13]

Launched in April 1965, INTELSAT I became the first commercial geostationary satellite. It had a limited communication payload and a small spacecraft antenna. These limitations required the use of very large aperture earth station antennas and high power

transmit amplifiers.[14] INTELSAT has since evolved through seven generations of satellites, growing from 240 telephone circuits on INTELSAT I to 13,000 plus two TV channels on INTELSAT V. INTELSAT VI, with its frequency reuse, advanced digital compression, and 32 kilobit per second capabilities, can handle up to ten times the capacity of INTELSAT V/V-A.[15] By the 1970s they had so much excess capacity that they began to lease this capacity for use by domestic operators who could not afford their own satellites. Many of the underdeveloped nations in South America, Africa, and Asia jumped at this opportunity.[16]

In parallel with INTELSAT's development have been a number of regional systems starting with the 1965 launch of Russia's high northerly elliptical communications satellite, MOLNYA. Others include the Russian geostationary orbital system, STATSIONAR; the Indonesian system, PALAPA, launched in 1976; ECS, the 1983 launched European system; and ARABSAT, launched in 1984.[17]

The first domestic communications satellite was the twelve transponder ANIK A, launched in 1972 by TELSTAR Canada. That same year also saw the FCC (Federal Communications Commission) reverse itself in the "open skies" decision and thus opening the door

for U.S. companies to compete against COMSAT.[18] The first U.S. domestic satellite was the 1974 launched WESTAR I. This was soon followed by the RCA SATCOM satellites and by COMSAT's COMSTARs.[19]

The use of satellites in the cable industry began on September 30, 1975 with HBO's live broadcast of the Mohammad Ali-Joe Frazier fight. Its success convinced HBO to distribute all of its programming by satellite. Most major programmers soon followed this lead. Initially, they all used RCA's SATCOM I, since Earth stations could only receive from one satellite at a time. A spin-off of satellite cable programming has been the home satellite television industry. The 1979 deregulation of receive only Earth stations, in the U.S., allows consumers to purchase, install, and operate satellite antennas in their backyards.[20] By law, users are required to pay for the programs which are receive but it is estimated that few actually do.

The use of satellites is now standard in the broadcast industry, for program distribution in North America. Satellites are now used almost exclusively, by networks, to get programs to affiliated stations. The first to do so were National Public Radio and the Public Broadcasting Network. Since March 1978, they both have been using the WESTAR satellite system for

program distribution.[21] Corporate use of satellites for communications has grown faster than expected in some areas and not as fast as was originally expected in others, growth though, has been constant.[22]

Satellite environment. It should be helpful, in reading the rest of this document, to have an idea of the type of environment in which satellites are typically required to operate. The first area to be discussed is space radiation. Uncontrolled it has the potential to cause severe damage to satellites and their electronic components. This damage results from three types of radiation. The first of these is ultraviolet radiation, mostly from the sun. It acts indirectly by eroding thermal coverings resulting in increased satellite temperatures.[23] Proper design can easily overcome this potential hazard.

The two most potentially serious types of space radiation, to electronic components, are high energy cosmic particles and electrons which travel in from outer space. They often have sufficient energy to penetrate the skin of a satellite. Electronics are usually not immediately hindered by this form of radiation but accumulate an effect over a period of time. Components, in geostationary orbit, typically receive a total dose of 100,000 rad(Si) in a seven to

ten year lifespan. This would be considerably higher if not for the five millimeters of shielding afforded electronic equipment. Commercial electronics are tested to withstand a total dose of at least 300,000 rad(Si) to ensure that they exceed satellite life expectancy.[24] Military systems are often specified for much higher levels. In addition they require additional measures for protection against X-rays which are released by nuclear explosions. Protection measures and levels are typically not discussed in open sources.

The second component of the space environment is severe temperature extremes. Temperatures often range from 60 to 420 degrees Kelvin, easily severe enough to destroy most electronic devices. Often worsening the situation are rapid temperature swings, causing thermal stress. With convection impossible in space, active and passive controls, such as heaters and surface treatments, are required to maintain a stable interior spacecraft environment.[25]

A third element of the space environment that must be protected against is solar flares. They can potentially cause severe electrostatic discharge. If left unguarded against, such a discharge could result in the destruction of electronic components. Severe

solar flares are almost impossible to protect against and thus, the only recourse available to operators is to power down their spacecrafts. Fortunately, solar flares are somewhat predictable in nature and do not last for long durations, thus, minimizing the impact on the satellite system.

Another element of a satellite's environment is absence of an atmosphere. Operation in a vacuum keeps the satellite from corroding but at the same time exposes it to destructive factors. One of these is the constant bombardment by charged particles and ultraviolet radiation, resulting in electrostatic discharges. The potential hazard of this is the destruction of electronics. Another problem is that without an atmosphere, friction increases, lubricants tend to evaporate, resulting in moving parts seizing up. A final consequence, of operation in a vacuum, is outgassing or perspiration, often of sealants and paints. These gasses can settle on sensitive optical surfaces, causing permanent damage.[26] None of these conditions can be shielded against and thus, space-qualified components, which are tested to survive such an environment, must be used.

Communication satellites must also be devised to survive the physical stresses of launch. These

include the following: 1. Compression forces, caused by changes in acceleration due to the burning of fuel by the launch vehicle. As a result, many satellites experience gravitational acceleration or "g" forces. 2. Mechanical shock, created by sudden changes in the launch, such as fairing jettison, satellite hold down clamp release, and booster separation. 3. Acoustic noise shock, resulting from sound waves bouncing off the earth and entering the spacecraft or from rocket booster velocities entering the transonic region. 4. Random vibration, caused by propellant combustion in rocket engines. 5. Sinusoidal vibration, experienced during both lift-off and in flight. The most violent form, caused by fuel line resonance, is referred to as the pogo effect.[27] If not guarded against, the cumulative effect of all of these stresses can result in severe satellite damage.

To ensure environmental survival, a satellite must meet stringent quality standards. Only the best individual components are accepted for use in space. The equipment, built from space-qualified components, are tested, at both board and finished product level, to ensure operation under the harshest of conditions. This equipment is then used to construct subsystems which in turn are assembled into a satellite. The

subsystems and satellites are again space-qualified to test for survivability. In addition, redundancy is used to guarantee continued operation of critical systems. Even with all the precautions, systems and satellites fail because the cumulative effects, of the space environment, eventually take their toll.

Types of Satellites

Satellites are complex pieces of hardware. Factors influencing their design include where they are located, what they are required to do, and how long they are expected to perform. The large amount of bandwidth available at multiple frequencies plus their accessible coverage make satellites austerely viable for many applications.[28] As Ambassador Diana Lady Dougan, U.S. Coordinator and Director, Bureau of International Communications and Information Policy, from 1986 to 1988 said, "As outposts above our heads, satellites increasingly serve essential needs of the world.[29] Discussed in the following sections are the types of satellites used to fill the world's various needs.

Broadcast service. Television is often strongly associated with satellite communications. Originally intended as relays for network and cable

television systems, satellites used for television transmission are becoming de facto direct broadcast satellites (DBS). Their signals are received by a large number of private individuals using three meter or greater receive only earth terminals. Satellites, such as GALAXY III, TELSTAR 301, and WESTAR IV, used in the U.S. cable industry, transmit signals using 24 downlink center frequencies spaced 20 MHz apart and ranging from 3720 MHz through 4180 MHz. Each channel is 40 MHz wide with alternating polarization used to prevent interference between adjacent channels.[30] This scenario is presented as a typical transmission scheme and may not represent that which is used by other U.S. and overseas cable satellite systems.

True direct broadcasting involves the airing of signals "intended" for individual reception and is characterized by powerful signals.[31] These signals, up to 100 times stronger than conventional signals, require no ground amplification. Direct broadcasting does require the use of antennas but, they can be as small as one foot in diameter. Systems such as these have been successful in isolated areas, like Canada's northern territories but seem to pose no real threat to cable systems, as was originally thought. This is due to both the strength of the competition and also

to the limiting factors presented by the powerful DBS signals.[32]

Fixed service. A fixed satellite service is radio-communications between earth stations at fixed points using one or more satellites.[33] Traditionally these services have included telephone, telegram, and telex trunk services as well as the distribution of television programs. This last category, in recent years, has made the distinction between broadcasting and fixed services less well defined. Operation in the fixed service arena is presently limited to three bands. The oldest and most used is the 6/4 GHz "C" band. Coming into wider use now is the 14/11-12 GHZ "Ku" band and finally the newest a least used is the 30/20 GHz "Ka" band. Details of these bands will be given in later sections.

Mobile service. A mobile satellite service involves radio-communication between one or more space stations and mobile earth stations using very small antennas. They can be subdivided into three categories: aeronautical, land, and maritime mobile satellite services, and typically include emergency and distress operations.[34] Mobile satellite services are becoming more popular because of their inherent

ability to overcome many of the obstacles of mobile terrestrial long distance communication. Obstacles include; loss of reliability due to fading, spectral congestion, and long access times.[35]

Examples of systems which provide Maritime satellite services include the international INMARSAT system, the U.S. Navy's FLEETSATCOM, the USSR Volna system, and the Japanese Aeronautical and Maritime Engineering Satellite (AMES). The primary function of these systems is to provide reliable ship to ship and ship to shore communications. Much less refined than maritime are the land mobile satellite services. These include communication with vehicles in remote and underdeveloped areas, distress communications for vehicles in remote areas, and emergency service in disaster areas. Aeronautical mobile systems, such as AEROSAT, were designed to provide added communication capabilities between air traffic control centers and aircraft. When first introduced, they did not catch on very fast but their future is now considered much better now that INMARSAT has entered the aeronautical services arena. The FCC has now allocated 18 MHz of bandwidth for use by all U.S. aeronautical and land mobile communications. A band of 1,549.5 - 1,548.5 MHz has been set-up for downlink and 1,651 - 1,660

MHz for uplink communications. Aeronautical mobile is listed as the priority occupant for both bands.[36]

Search and rescue. The primary member of this satellite category is RDSS (Radio-Determination Satellite Service). It assists in accurate location and tracking to include finding lost children, downed aircraft, stranded vehicles, and distressed boats.[37] The major U.S. player in this arena is Geostar Corp. Their initial attempt at RDSS, in 1986, ended when their GTE SPACENET payload failed a few days after launch. Operation officially started in 1988 with the successful launch of two GEOSTAR payloads aboard SPACENET satellites. The next step for the Geostar Corp. is the launch of two dedicated RDSS satellites (scheduled for space shuttle launches in January and October, 1992). Geostar has also gone international with a 15% ownership in LOCSTAR, the French space agency clone to the GEOSTAR operation. In addition, Geostar is attempting to make arrangements to place one of their payloads on a Chinese communications satellite. Geostar's initial customers have mostly been trucking companies but they now are receiving a trial test by the Coast Guard (for use on all their vehicles) and the FAA (for use on small aircraft).[38]

Intersatellite relays. Geostationary relay satellites allow the number of ground stations to be minimized without sacrificing global coverage.[39] An important member of this satellite class is NASA's, 1980 launched, Tracking and Data Relay Satellite System (TDRSS). Its function is to collect data from low earth scientific and experimental satellites and relay the data back to NASA ground stations.[40] This function is very crucial because it is estimated that NASA scientific missions generate over 6000 terabits of data per year, which must be relayed to processing centers. With similar benefit motivation, most other work, in the area of data relay satellites, has been sponsored by the U.S. Defense Department. An example is their 1988, $7.4 million, contract, with Defense Systems Inc. of McLean, Virginia, for construction of a constellation of eight "Microsats," extremely small UHF communication satellites, designed for the relay of data.[41] The military uses the 60 GHz and optical spectrum bands to relay information among satellites in geostationary orbit, while other systems, such as TDRS, use standard "C" and "Ku" frequency bands for intersatellite communications.

Other application satellites. Many types of satellites rely heavily on communication's systems in

the performance of their missions. A meteorological satellite relies on communication to relay the data used in weather forecasting. Satellites allow data to be gathered across the globe and then forwarded, in real time, to forecasters. Early ones were placed in low earth orbit because of limitations in launch and camera/instrument technology. In the 1970s, Europe, Japan, the U.S., and India joined forces to launch a family of geostationary weather satellites. Advances allowed these satellites to be as accurate as their low earth predecessors.[42] In recent years, the U.S. has returned to low earth, using the 102 minute orbit NOAA (National Oceanic and Atmospheric Administration) satellites for weather prediction.[43]

A second category of satellite, which relies heavily on communication, is remote sensing. Remote sensing from space began in 1947, when a U.S. rocket carried sensing equipment into the upper atmosphere and was further carried on by the manned flights of the 1960s. The first dedicated earth observation system was the 1972 launched, ERTS (Earth Research Technology Satellite), later renamed LANDSAT I. In spite of limited success, the LANDSAT program made many countries uncomfortable due to the uncertainty concerning the types of data being obtained. In an

attempt to limit fears, these satellites were made part of the U.S. open skies policy and all countries were given access to collected data.[44]

Another type of satellite which extensively use the geostationary orbit is military. The guess is that between one-fourth and one-third of all U.S. launched satellites have military related functions, with an even higher figure estimated for the Soviet Union. The People's Republic of China is the only other nation to actively use military observation satellites. Military satellite uses include: early warning, reconnaissance, and surveillance and often their capabilities far exceed those for commercial systems.[45] Examples include DSCS (Defense Satellite Communications System) and the previously mentioned FLEETSATCOM. The frequency bands used most by these systems are UHF and SHF, with more recent emphasis being placed on EHF and optical. The one element which sets military satellites apart from others is their reliance on communication security (COMSEC).

Finally, to be addressed are the positioning, navigation, and geodesy type satellites. In common, is their reliance on accurate position and position change measurements in relation to time and space. Real time position determination has become ever more

important for navigation on both the sea and in the air. It is also useful in civil engineering, rescue operations, resource exploration, and environmental planning. An example of such a satellite is the GPS (Global Positioning Satellite). Geo-dynamics uses satellites as tools to study the internal structure and dynamics of our planet. This includes measuring earthquake induced land movement, monitoring polar movement, and the Earth's rotational period.[46]

Spacecraft Subsystems.

Maintaining a microwave communication system in geostationary orbit is not a simple problem. A satellite must provide a stable platform on which to mount the antennas, be able to station keep, provide electrical power for the communications systems, and also provide a controlled environment. These first three subjects will be addressed in the following sections, while the last area will be omitted due to its reference in a previous section. A knowledge of the power generating subsystem is necessary for two reasons. First, advanced communications payloads, that more efficiently use the GSO, will need enhanced power generation. Second, more advanced alternative power generating options will be necessary if more stringent station keeping requirements are placed on

geostationary satellites. Knowing current station keeping constraints and how they are sustained is essential in recognizing the physical limitations of the GSO. Presently, the physical limits, are not an issue but advances in other areas may push these limits in future years. Finally, an understanding of communication systems is important, because these advances will lead to the largest gains in orbital capacity and efficiency. Also addressed will be an overview of communication satellite frequencies and who uses them.

Power generation and conditioning. Two types of power generators are used in space operation. The least used is nuclear power. It is primarily used on space probes but may get more consideration if future operations require higher levels of on orbit power. For now the dialogue will focus on solar power, which is the primary power source for satellites operating in the geostationary orbit. It uses silicon based photo-voltaic cells, cemented on large solar panels, to produce power. Spin stabilized satellites, such as INTELSAT VI, use solar arrays attached directly to its cylindrical outer skin. Total power generated by INTELSAT VI is about 2 kilowatts through its expected 14 year life. A second type of solar array is the

solar sail.[47] Because of their size and shape, they must be folded during launch and then extended when in orbit. Tracking devices are used to ensure that all solar cells are exposed to the sun, and thus they can produce more power than cylindrical arrays having a comparable number of cells.[48]

Maintaining service during times of little or no sunlight requires the use of batteries. The most used type is nickle-cadmium (Ni-Cd), but developments in nickle-hydrogen (NiH_2) batteries have resulted in significant improvements in power to weight ratio and thus are, probably the future battery of preference. Batteries are charged by the solar arrays during off load times and are then available when needed. Two to three batteries are usually installed to provide adequate capacity as well as redundancy. A satellite power subsystem contains switches to turn loads on or off to protect batteries from overcharge or draining. Some are switched automatically when certain settings arise, while others are activated by ground command. Manual override of automatic switching is possible by telemetry command in cases of unforeseen problems.[49] Batteries are mission critical for satellites which must operate full service both day and night.

Spacecraft have a main power bus which runs from the solar array and branches out to all loads. Batteries are connected in parallel so that they may be accessed in times of need. If all the loads were activated at the same time, power would be inadequate and batteries would be needed to supplement. Another way to regulate the power is with power conditioning. This involves the use of regulators which sense the amount of load and then provide the amount of power necessary to meet demand. Three basic types are used (shunt, array switching, and sunlight), but details of how each works is not relevant to this paper.[50]

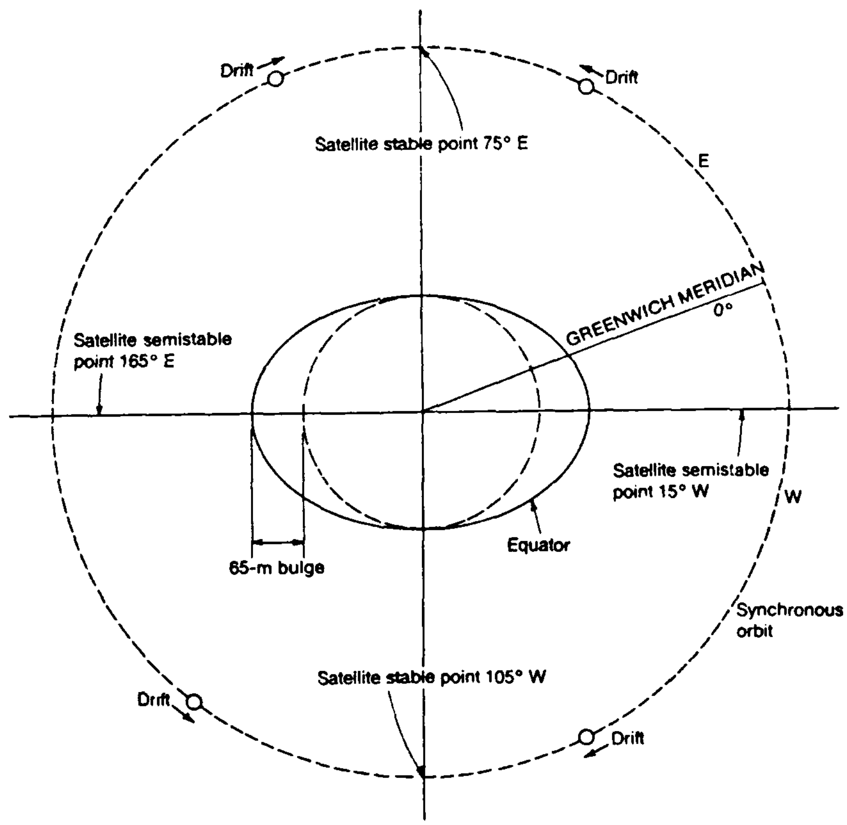
Advances are either here or on the horizon which should be capable of meeting near future power consumption needs. Two such advances are detailed below. Under development are gallium arsenide (GaAs) solar cells which promise to offer 18-19% efficiency at start of life, compared to 13% for silicon cells. They also exhibit 50% less degradation in the face of severe radiation and thermal environments. The hope is that their high price and thickness can be brought down, to justify their use. The previously mentioned nickle hydrogen batteries have a storage capacity of 22 watt-hours/lb compared to 18 for nickle-cadmium. They can also be discharged to 70-80% of capacity vs.

50-55% for nickle-cadmium. These two facets combined results in the production of twice the energy density of the older cells over a 15-year mission.[51] As far as the near future is concerned, multi-junction solar cells, able to produce over 25% efficiency, should be developed and ready for use by the early 1990s. Also batteries based on sodium, sulfur and lithium should provide weight to power reductions of 50% to 75%, in the next decade.[52]

Station keeping. Every satellite which is to operate in geostationary orbit is assigned a nominal orbital position. Once in orbit, it will inevitably drift away from this position due to the effects of several forces, mainly 1. solar and lunar gravity and radiation pressure which cause the orbital plane to incline about 0.85 degrees a year. Left uncorrected, the satellite will drift to an inclination of 14.67 degrees in 26.6 years and then back to zero where the cycle is repeated. 2. "Asymmetric Earth potentials, caused by the non-spherical and inhomogeneous Earth." There are two points of stable equilibrium in the GSO (at longitudes 105 degrees West and 75 degrees East) and two unstable positions 90 degrees away from each of these. A satellite in any other position will

drift along the equator.[53] Figure 2.1 illustrates how a satellite drifts along the equator.

A satellite uses thrusters and microjets to overcome drift forces. Compensation for drifts along the equator (as well as relocation to a different GSO



Source: Timothy Pratt and Charles W. Bostian, Satellite Communications, (New York: John Wiley & Sons, Inc., 1986) p. 56.

Figure 2.1. Geostationary Satellite Drift

position) is termed East-West station keeping. It is performed by applying thrusts in the orbital plane. Jets are pulsed once every 2 to 3 weeks and result in the satellite drifting back through its nominal position, coming to a stop, and then recommencing the drift along the orbit until the jets are pulsed again. Current ITU (International Telecommunication Union) regulations require GSO satellites to maintain an East-West station keeping accuracy of better than 0.1 for "C" band and 0.05 degrees for "Ku" band.[54]

Compensation for increases in the inclination angle corresponds to North-South station keeping and requires a thrust to be applied perpendicular to the orbital plane. Once the inclination angle reaches its specified limit, jets are pulsed to return the inclination to zero. Counteracting jets are pulsed when the inclination is at zero to halt the change. North-South station keeping is far more costly, in terms of fuel expenditure, but has the same tolerance as for East-West station keeping.[55]

Instructions from the earth station, over the TT&C (Telemetry, Tracking and Command) communication link, are used to make orbital corrections. Changes are usually made by the same jets used for altitude control. Current station keeping systems will allow

INTELSAT VI to maintain orbit for 13-14 years with Ford's INTELSAT VII expected to achieve a station keeping life of 19 years. Pushing satellite life past 20 years is pointless due to the imminent economical obsolescence of satellite technology.[56]

Due to communications systems limits, active satellites, in the geostationary orbit, are typically spaced at least 2 degrees apart. Under these limits, satellites operating at the same frequency and signal polarization can not be spaced closer than 1475 kilometers apart. Thus, without advanced communications methods, the maximum number of satellites that can be held by the GSO is limited to 180 for each operating frequency band (180 in "C" band, 180 in "Ku" band, 180 "Ka" band, and etc.). Some satellite spacing is 3° and 4°, farther limiting the number of satellites. Using the current station keeping limits of 0.05° (a window of less than 74 kilometers per side), placed on "Ku" band satellites, at least 3600 satellites can be placed in the GSO without serious possibility of collision. To emphasize how well satellites operate at close quarters, it is a normal practice to bring one satellite close to another, within the slot, when traffic is being transferred from an old satellite to a new one.[57] In addition, it is also commonplace to

have spare satellites occupying the same nominal slot as their active cousins.

This idea was advanced by a 1980 report which estimated that ten satellites, each with a 100 meter cross sectional area, placed in the same nominal slot would have a probability of collision of only 0.00004 per year or on average one collision, between active satellites, every 400,000 years. The report went on to note that, under these conditions, satellites were 25 times more likely to collide with dead satellites than with active ones.[58] Taking this study one step farther, using "Ku" band spacing of 0.05 degrees will allow 20 spacecraft to occupy the same nominal orbit position. Even under these circumstances, it is very unlikely that the chance of collision between active satellites will increase dramatically over that which was stated in the study.

Several important conclusions can be drawn, from this information. First, with current station keeping technology, communications advances have the potential to increase to 20 the number of satellites which can occupy a nominal 2^{o} orbital arc. Such an advance would even permit 20 satellites to operate at the same frequency within a nominal orbital position. Currently, without advanced communication techniques,

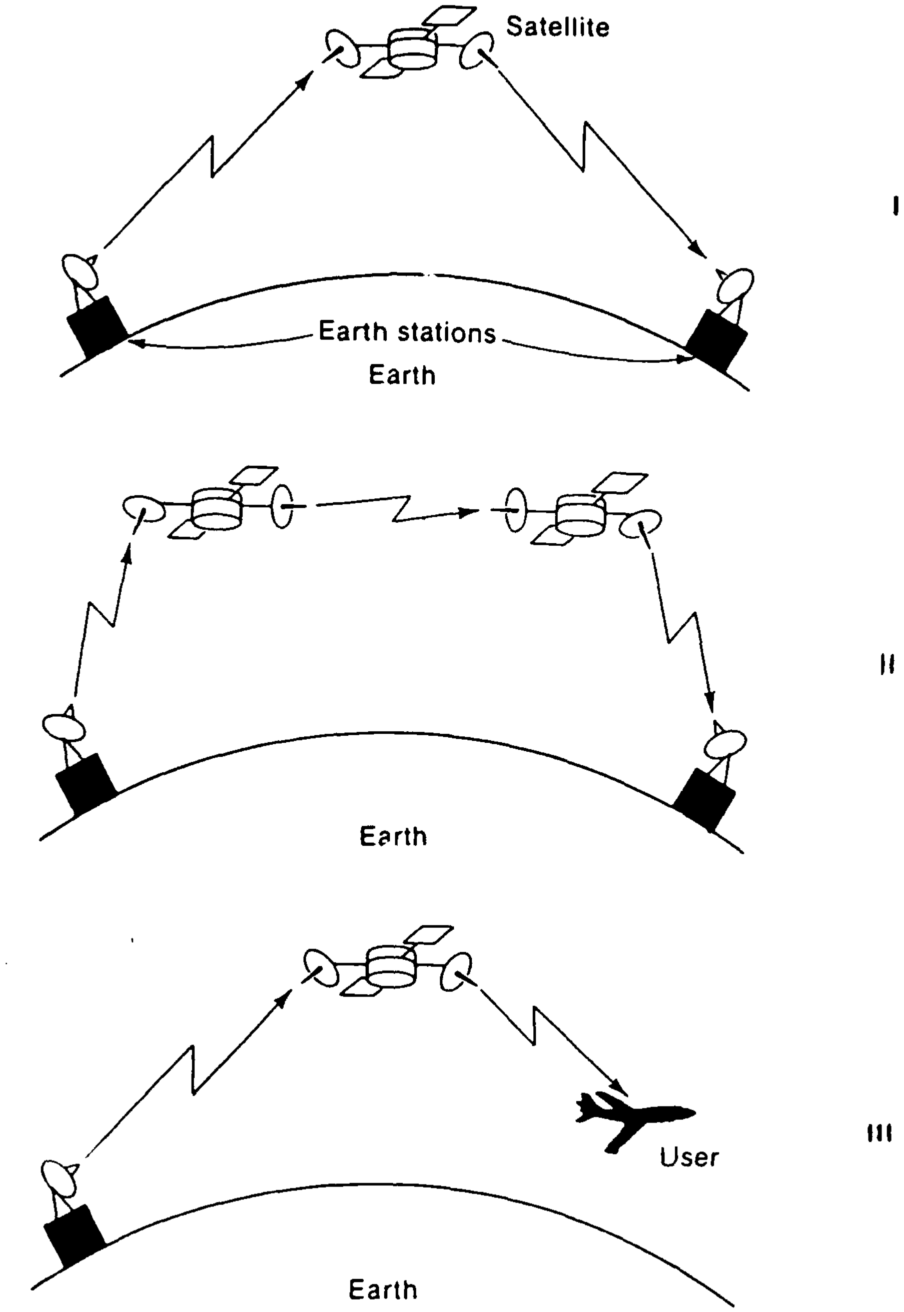
the only method to operate 20 satellites in the same nominal orbital position is to communicate using 20 different frequency bands. Second, power generation advances may permit even stricter station keeping constraints, with even more satellites able to occupy the GSO. Third, the more satellites in space, the more of a problem space debris and dead satellites become. Obsolete satellites must be removed from orbit prior to their death. If a satellite dies in orbit, some means must be developed for its removal. The most important point, though, is that it should be absolutely clear that current station keeping in no way limits the number of satellites which can now occupy the GSO.

Communication systems. Satellites typically have several communications systems with different functions. Types of systems include TT&C systems for satellite control, intersatellite communications, and satellite to ground communications systems. TT&C is similar in nature to the other two and will not be addressed in detail because, at present, it does not seriously affect the orbital congestion problem. One or both of the other two types of systems are used to transmit information from one ground station or user to another ground station or user by way of one or

more satellites. Figure 2.2 shows three satellite communications scenarios. As can also be seen from this figure, the major function of a communications satellite is to receive a radio signal, amplify it, and then retransmit it. Even advanced processing satellites, capable of data manipulation and on-board processing, deviate only slightly from this concept.

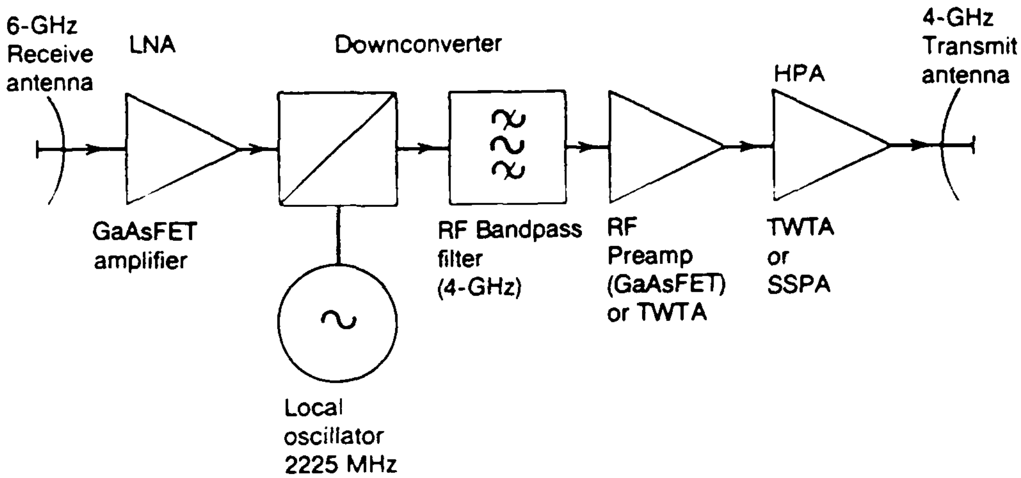
A satellite communications subsystem consists of three primary elements, a receiver, a transmitter, and an associated antenna. The transmitter/receiver combination is the transponder, with several often sharing a single antenna. The one-way transponder antenna package is known as a repeater. As the name implies, a repeater's purpose is to relay or repeat a message with the highest possible fidelity. Two-way communications requires at least two repeaters.[59] Figure 2.3 shows a simplified version of this set-up.

In a satellite communications system, signals are received and transmitted on separate frequencies to avoid interference. The transmitted frequency is usually lower to aid in simplification of on-board high-power electronic circuits. One function of the receiver is to down-convert the carrier signal to its retransmission frequency without harming the baseband



Source: Robert M. Gagliardi, Satellite Communications, (Belmont, CA.: Lifetime Learning Publications, 1984), p. 5.

Figure 2.2. Satellite Communications Scenarios I. Ground-Ground, II. Ground-Crosslink-Ground, III. Ground-User Relay



Source: Timothy Pratt and Charles W. Bostian, Satellite Communications, (New York: John Wiley & Sons, Inc., 1986) p. 75.

Figure 2.3. Simplified Repeater

signal (information riding on the carrier). On-board manipulation may then occur after the baseband signal has been converted to a lower intermediate frequency (IF) for efficiency. Types of manipulation include filtering, demodulation, amplification, and rerouting of multiplexed signals. Upon completion, the signal is then up-converted and retransmitted.[60]

Satellite communication's receivers are solid state devices composed of a low-noise amplifier (LNA) and a down-converter. Field-effect transistors (FET) are used in most LNAs to reduce the effects of signal degrading thermal noise. The down-converter consists of a crystal oscillator and a frequency mixer. A

pure sinusoidal waveform is produced by filtering the oscillator output. The mixer multiplies the produced waveform with the received signal to produce a beat. The beat constitutes the down-converted carrier.[61]

A high power amplifier (HPA) is the primary device in a satellite transmitter. Power dividers, power combiners, power limiters, and pre-amplifiers may also be required for various applications. There are two types of HPAs, traveling wave tube (TWTA) and transistorized power (TPA) amplifiers. The former is more common and will be explained. An electron gun produced beam is accelerated by an anode into a slow wave tube. This wave tube consists of a helix-shaped RF conductor and a set of beam-focussing magnets. As the electron beam enters the tube, it interacts with the weak RF (radio frequency) signal being fed to the input of the helix. The interaction causes energy to transfer from the beam to the coil which produces a highly amplified RF signal at the coil output.[62]

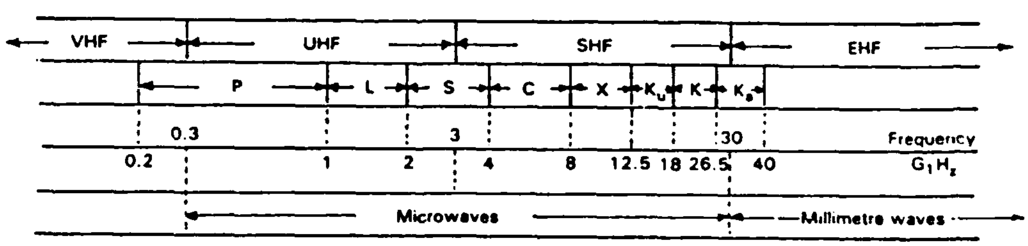
The most common spacecraft antenna, for area coverage, is the parabolic dish. They can produce a "global beam," with widths up to 17.3 degrees, from a synchronous orbit. This size beam will cover all the U.S. including Hawaii, Alaska, and Puerto Rico. Spot beams, with widths of 1 to 2 degrees, can be produced

by parabolic antennas to cover specified areas. The narrower the beam, the higher the gain and the larger the antenna aperture. Omnidirectional antennas are used in TT&C subsystems to ensure spacecraft command prior to altitude stabilization or in the event that stabilization is lost. Antennas can be steerable or fixed with spot beams usually being steerable. A mechanically or electronically despun core is used by spin stabilized satellites to keep their antennas oriented towards the earth.[63]

An important part of any communication system is its transmission frequency. The first part of the radio spectrum to be used extensively for satellite communications was the "C" band. "C" band is still the dominant band used for satellite communications, with operation prir :ily limited to fixed satellites. It uses an uplink center frequency around 6 GHz and a downlink center frequency around 4 GHz (designated 6/4 GHz). Another band used for fixed satellites is the "Ku" band. Portions of this band are not shared with terrestrial services and thus it has advantages over "C" band. "Ku" band has three primary operating areas. First, are the 14/12 GHz frequencies, used in Region 2 (North and South America) for fixed service. Second, is the 14/11 GHz segment used by the rest of

the world for fixed satellite service. Last, is the 18/12 GHz segment reserved for broadcast services.[64]

The frequency bands below "C" have been found to be effective for communications services requiring the use of mobile and transportable transponders. The reason being, these bands ("L" and UHF) require the use of only simple antennas. Two bands used almost exclusively by military systems are the "S" and "X" bands. The former being centered at 2 GHz while the later has an uplink range of 7.90 to 8.40 GHz and a downlink range of 7.25 to 7.75 GHz. A final band of interest is the 30/20 GHz "Ka" band which should find increased commercial use in the 1990s. Its one main drawback is the potential for increased atmospheric propagation loss at these transmitting frequencies.[65] Figure 2.3 shows the radio frequency spectrum layout in more detail.



Source: Geoffrey E. Lewis, Communications Services Via Satellite, (Oxford: BSP Professional Books, 1988), p. 3.

Figure 2.4. Frequency Bands and Designations

Geostationary Orbit

> "In his famous Wireless World article of 1945, entitled `Extraterrestrial Relays,' Arthur C. Clarke suggested that a true broadcast service giving constant field strength at all times over the whole of the globe would be invaluable, not to say indispensable, in a world society."[66]

He went on to conclude that any satellite placed in a circular equatorial orbit at an altitude of 35,800 kilometers (22,245 miles) would have an angular velocity which matched that of the Earth. It would, thus, always remain above the same spot on the ground. This would allow the satellite to receive and relay signals from nearly 40% of the globe at the equator. As is typical with science fiction writers, Clarke had ideas far ahead of his time.[67] For as was noted earlier, it was not until the Russians launched SPUTNIK I on October 4, 1957, that rocket technology existed to place a satellite into even a low earth orbit. It was then six more years (eighteen years after Clarke conceived the idea) before SYNCOM II was launched to became the first geostationary satellite.

Today, communications, by means of satellite, is a well-known application of space technology. As predicted, the 24-hour geostationary (equatorial, circular-synchronous) orbit is invaluable to mankind in the pursuit of global communications. Because of its unique Earth-relative geometry and kinematics, it

provides many economic and operational advantages.[68] The result being the use of geostationary satellites for the majority of both domestic and international satellite communications.

Characteristics

The distance of a geostationary satellite, above the Earth's equator, is 35,786 kilometers. At this altitude, it takes a satellite about 23-hours and 56-minutes to complete the 264,930 kilometer orbit of the Earth. This equates to a velocity of 3.075 kilometers per second. It may be a surprise to some that a satellite's orbital period is not exactly 24-hours. The reason is that, as the Earth rotates around the sun, the period of one Earth rotation is different with respect to the sun (24-hours) than to the stars (23-hours 56-minutes). Thus, since orbits are defined in the star frame, the period of a truly geostationary satellite coincides with the sidereal (star) day rather than the calendar (sun) day.[69]

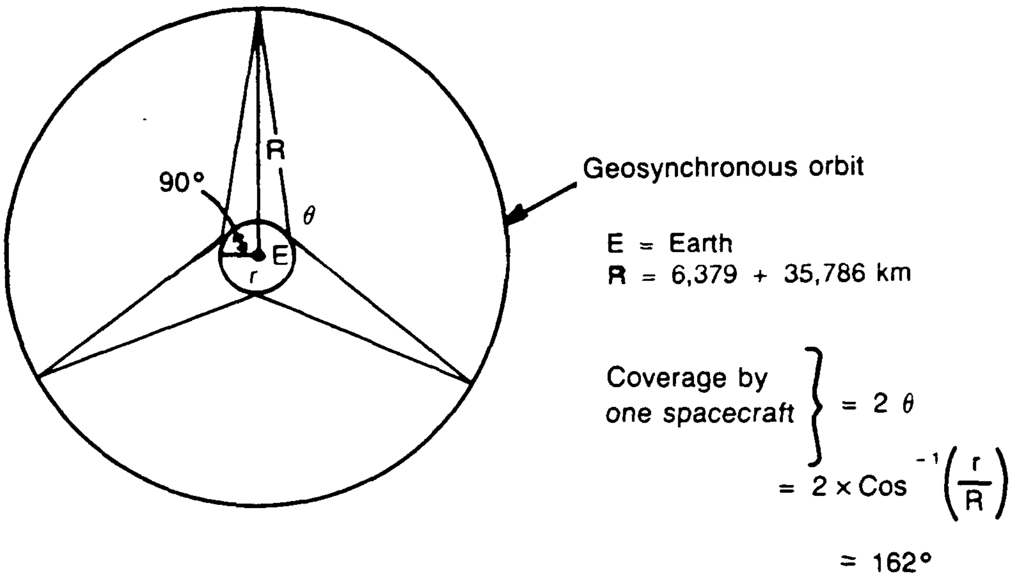
Advantages

Evidenced by their wide use, geostationary satellites provide many advantages to those who wish to use them for communications and other satellite related applications. They are synchronous with the

Earth's rotation and to observers on the ground they appear to maintain a fixed position in the sky. As Clarke suggested, a GSO satellite has a constant view of approximately forty percent of the Earth's surface at the equator and can, thus, maintain continuous communication with earth stations located within this area. Ground antennas, consequently, do not need to be continually reorientated to track the satellite. Hence, the cost of computer-assisted tracking systems is avoided.[70] These characteristics allow three satellites, equally spaced, to provide communications service to most of the populated areas of the world. An illustrative geometry of global coverage is shown in Figure 2.5.

With powerful earth stations that can receive signals at the horizon, a system of GSO satellites is able to service an area that extends in latitude from roughly 81.3 degrees north to 81.3 degrees south.[71] As many as 30 low altitude satellites would be needed to provide this same service.[72] With the majority of the Earth's population inhabiting this coverage zone, these systems in effect provide global communications service.

Most terrestrial communication systems demand repeaters to be placed at relatively short distances



Source: P.R.K. Chetty, Satellite Technology and Its Applications, (Blue Ridge Summit, PA: Tab Books Inc., 1988), p. 309.

Figure 2.5. Geometry of Global Satellite Coverage

from each other. Each repeater is a source of noise, with total signal degradation being a product of all the individual noises produced by each repeater. A satellite system typically has only one repeater and, thus, can provide signal quality orders of magnitude better than that provided by microwave systems. The standard bit error rate (BER) for a typical satellite digital transmission is 10^{-6} to 10^{-7} versus 10^{-5} for a common microwave system.[73]

A final advantage of geostationary satellites is their ability to provide continuous communication service 24-hours a day. The stationary orbit is in

sunlight more than 99 percent of the time (infrequent eclipses occur around midnight). This simplifies the generation and storage of power and reduces satellite temperature cycling.[74] Considering the many military and commercial advantages of geostationary operation, it becomes quite obvious why most countries of the world rely so heavily on this orbit in meeting their communications needs.

Limitations

At present, the number of satellites that can occupy the geostationary orbit is not limited by the threat of physical collision between active systems. The current 2 or 3 degree minimum orbital arc spacing limits, depending on region, are based on projected interference characteristics of adjacent satellite communication systems. Another limitation, already addressed, was the active compensation necessary for latitudinal and longitudinal drift.

Visibility from any given earth station may be East-West limited depending on antenna elevation and geographic coordinates. The lowest elevation in theory is zero but in practice, to avoid reception of excessive noise from the Earth, a value of 5 degrees is chosen as the lower limit.[75] Visibility is also an issue for countries which lie near the North and

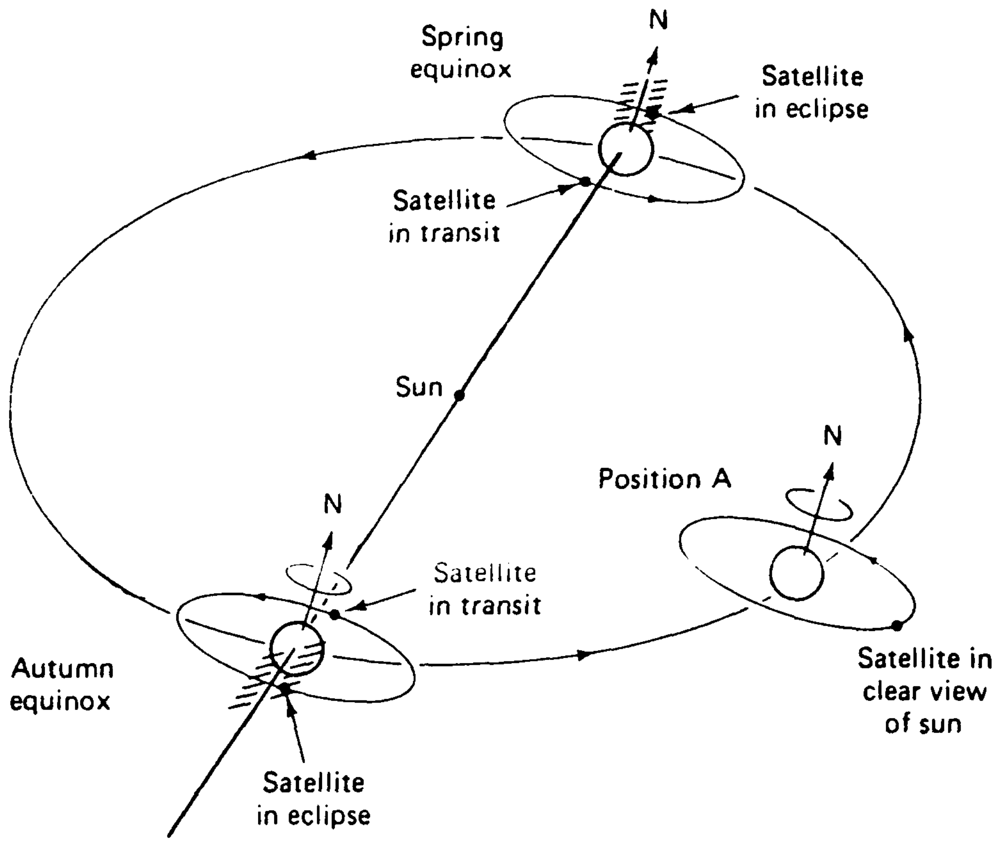
South poles. Theoretically, reception from a GSO satellite, is possible 81.3 degrees North and South of the equator, based on limitations related to Earth curvature. In practice, the visibility area is less due again to minimum antenna elevation requirements. Countries far away from the equator use satellites in highly elliptical polar orbits similar to the Russian MOLNIYA system. The Molniya spacecraft is visible for about 8-hours each day at apogee, with four such satellites able to provide 24-hour service, with a two hour overlap to aid in hand-off from exiting to entering spacecraft.[76]

When the Earth's equatorial plane is in line with the plane of the Earth's orbit around the sun (the ecliptic plane), a geostationary satellite will be eclipsed by the Earth. Since the equatorial plane is tilted at an angle of 23.4 degrees to the ecliptic plane, satellites are in full sunlight for most days of the year. At the spring and autumn equinoxes the sun does cross the equator, placing the satellite in the Earth's shadow (equinoxes occur the first days of spring and autumn). The resulting eclipses begin 23 days before equinox and end 23-days after equinox. The eclipse lasts about 10-minutes at the beginning and end of the period, and increases to a maximum

duration of 72-minutes at equinox. During an eclipse solar cells do not function and satellite power must be battery supplied.[77]

Another equinox event is referred to as a sun transit outage. It occurs when the satellite passes between the Earth and sun in such a way that the sun comes within the earth station's antenna beam. The sun will appear as an extremely noisy source which completely blanks out the satellite signal. This effect lasts for short periods each day for about six days around the equinoxes. The frequency and duration of the sun transit outage depends on the latitude of the earth station, with typical outages lasting around 10-minutes.[78] Figure 2.6 illustrates both of these effects, with Position A showing the satellite in clear view of the sun. Important to note is that eclipses and sun transit outages are not limited to geostationary satellites but also effect satellites in other orbits.

Two limitations which effect all satellites, but geostationary satellites to a greater degree are propagation delays and path losses. The single hop signal propagation delay for geostationary satellites is about 0.25-seconds. Though this delay is greater than that experienced by other transmission mediums,



Source: Dennis Roddy, Satellite Communications, (Englewood Cliffs, N.J.: Prentice Hall, 1989), p. 55.

Figure 2.6. Satellites in Eclipse and Transit

it is easily compensated for, provided there is no echo.[79] An echo occurs when there is a mismatch at the receiving end of the satellite link and appears as a repeat of the speakers voice, appearing at the transmitting end about 0.5-seconds after spoken. An echo canceler can be used to eliminate echos when they occur. It does this by detecting the presence

of a delayed version of the forward signal in the return path and then dynamically canceling it out using a transversal filter. Another way to combat echos is with an suppressor. The problem with these devices is that they do not work well on full duplex communications links.[80] The signal attenuation path losses are equal to $(R \times f)^2$ where "R" is the path distance and "f" is the frequency of operation.[81] Attenuation losses are greater in high precipitation areas and at extreme latitudes (due to the greater distance signals must travel through the atmosphere).

Overcrowding

Since the first geostationary satellite was launched in 1963, the number of satellites in the GSO has continued to grow. The number using this orbit has increased by about 18 percent per year for the last decade. The geostationary orbit, like the radio spectrum, is viewed by many to be a limited natural resource. Although it can theoretically hold a host of satellites without any serious risk of collision, the number that can operate in the GSO on a given frequency without consequent radio interference is much more limited.[82]

According to a 1985 FCC advisory report, by the end of 1984 there were a total of 138 satellites

of all types in the GSO. Of these about 80 were for communication purposes, with 48 of them having been launched since 1979. Only about 14 of those launched during this period served the developing countries. The report also noted that another 160 additional communication satellites including replacements, had been proposed for launch by the end of 1989. Even with the launch mishaps that have occurred during the last five years, the growing number of satellites in service is beginning to create a difficult situation for countries needing orbital positions in specific segments of the orbital arc. It is also becoming increasingly difficult, in certain areas, to secure specific frequency bands.[83] The results are that certain portions of the orbital arc and frequency spectrum are becoming overcrowded.

Over the last decade, the pressing issue of geostationary orbital crowding has developed into a highly politically-charged debate, with two divergent points of view. The lesser developed countries, hold that while they are becoming more technologically and economically able to place a satellite into GSO, the orbital positions available for their use are rapidly disappearing. Developed nations argue that by the time these nations are ready to launch satellites,

technological advances will have made additional slots available. Thus, the developed nations feel that a more laissez-faire approach to GSO regulation is in order, while the developing nations call for strict planning procedures and regulations.[84] This conflict and the organizations carrying it out will the subject of Chapter III.

NOTES-CHAPTER II

[1] Bruce R. Elbert, Introduction To Satellite Communication, (Norwood, MA.: Artech House, Inc., 1987), p. 1.

[2] Hussain A. Haddad, "Satellite Communications," In Telecommunications: An Interdisciplinary Text, Ed. Leonard Lewin. (Dedham, MA.: Artech House, Inc., 1984), p. 566.

[3] Haddad, p. 565.

[4] Timothy Pratt and Charles W. Bostian, Satellite Communications, (New York: John Wiley & Sons, Inc., 1986) p. 1.

[5] Robert M. Gagliardi, Satellite Communications, (Belmont, CA.: Lifetime Learning Publications, 1984) p. 7.

[6] Geoffry E. Lewis, Communications Services Via Satellite, (Oxford: BSP Professional Books, 1988), p. 1.

[7] Spot beams actually start to change this, but even they are much less distance sensitive than terrestrial alternatives.

[8] Walter L. Morgan and Gary D. Gordon, Communications Satellite Handbook, (New York: John Wiley & Sons, Inc., 1989), pp. 3-7.

[9] Nicolas Mateesco Matte, Aerospace Law: Telecommunications Satellites, (Toronto: Butterworth & Company Ltd., 1982), pp. 2-5.

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[46] N. Jasentuliyana and Ralph Chipman, Eds., International Space Programmes and Policies, Proceedings of the Second United Nations Conference on the Exploration and Peaceful Uses of Outer Space (UNISPACE), Vienna, Austria, August 1982, (Amsterdam: Elsevier Science Publishers B.V., 1984), pp. 38, 40.

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[84] White, p. 10.

CHAPTER III

REGULATORY BACKGROUND

Who are the organizations and agencies levied with the responsibility of planning and monitoring the use of the geostationary orbit? What has been their plan of action and how has it changed over the last twenty-five years? These are the questions that are addressed by this chapter.

One observation that should be made before answering these questions concerns the time frame for regulatory versus technical change. Upon researching both the technical and regulatory areas of satellite communications, it became noticeable that there were vastly different time lines associated with technical and regulatory progress. With technology, it is not uncommon for innovative discoveries to occur rapidly, sometimes on a daily basis. Regulation on the other hand, takes time to implement. Slow is sometimes not all bad, but in this case it seems that many of these problems could have been solved in the time it takes regulators to figure out how they should be resolved. Technology sometimes so out paces regulation that in

the case of GSO crowding the regulatory work of the past ten years is being "over come by events," namely technological advances. Stated bluntly, three global conferences (plus other minor ones) spread out over ten plus years is too long to spend on a problem that may very well become obsolete in several years.

Regulatory Bodies and Other Relevant Agencies

The following words delivered by Parker Borg, then acting U.S. Coordinator and Director, Bureau of International Communications and Information Policy (CIP), before the Subcommittee on Communications, on April 19, 1988, shows that even some members of the regulatory community are becoming impatient with the current state of international regulatory efforts.

> "The International Telecommunication Union (ITU), INTELSAT [International Telecommunications Satellite Organization], and INMARSAT [International Maritime Satellite Organization] play important roles in establishing the 'rules of the game' governing international interdependence in the field of Telecommunications. But the process of achieving consensus within these organizations has become increasingly difficult and complex. In the ITU, the competition for access to the radio frequency spectrum and geostationary satellite orbit has gone beyond the technical process to become one flavored with political and economic consideration."[1]

It is safe to say that Mr. Borg's notions are not the consensus view of the entire international regulatory community nor is it unreasonable to believe that his

opinion would be much different if the United States was today the beneficiary of favorable ITU rulings. The conclusion that should be drawn from these words are that international regulatory procedures are and probably always will be processes driven by economic and political considerations.

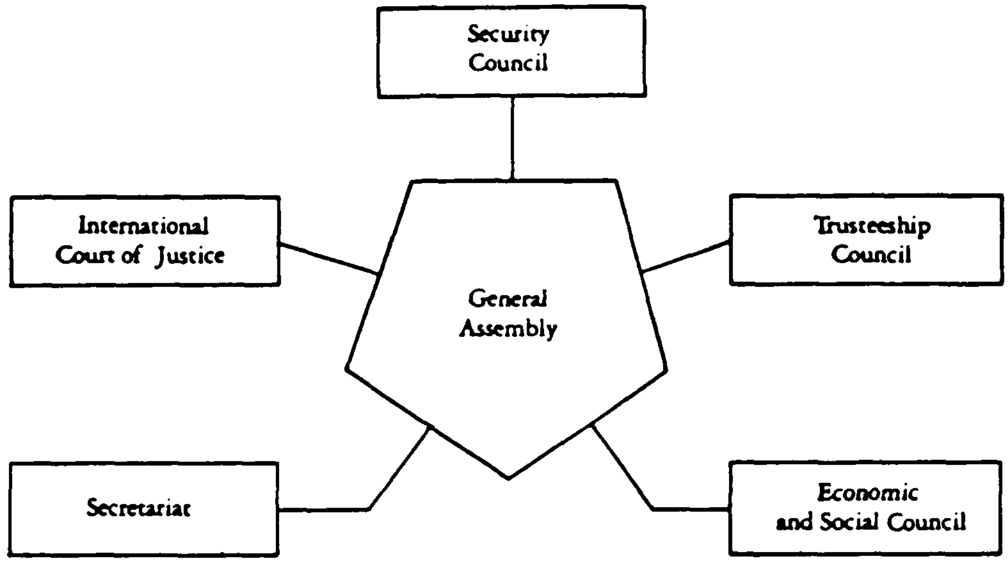
Unfortunately the problems in this area are not just limited to the international community but also encompass domestic regulators, to include the U.S. Nations and organizations not only have their own unique way of doing business but also have self interest in mind when implementing policy. These differences have led to many of the problems that have arisen over the planning of the GSO arc. For example, the countries with the technological and financial means to launch communications satellites are typically going to be the ones implementing and supporting policies which allow the most free use of satellite resources. Policy decisions, however, are usually made by the majority, of which most do not possess the necessary resources to launch satellites but through the regulatory process wish to guarantee that option should the opportunity present itself. Here in lies the developed vs. underdeveloped nation

conflict that has slowed to a crawl the regulatory process for GSO planning.

United Nations

The United Nations (UN) and its governing arms are in the middle of and provide the forum for discussion, adoption, and implementation of aerospace law and policy. Being a political, intergovernmental international body, the UN is forbidden from playing any part in the ownership, launching or operation of satellites but it has created an international legal system, whose responsibility it is to regulate space activities to include telecommunications satellites.[2] The United Nations ensures that all nations act in accordance with voted upon treaties and regulations and provides for the accountability of those nations and or organizations that choose not to comply with international laws. Figure 3.1 shows a block diagram of the UN and its related agencies, with the bodies charged with outer space policy shown in Figure 3.2.

General Assembly. The United Nations General Assembly (UNGA) is composed of a representative from all of the UN member nations. In matters of general nature, votes are taken on the one nation one vote principle, with majority rule. The Security Council

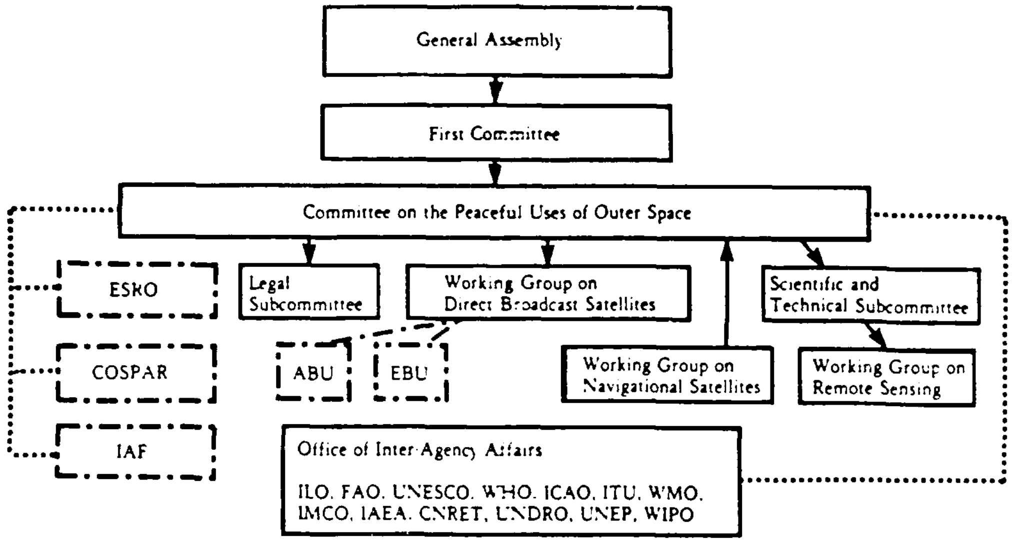


Source: Rita Lauria White and Harold M. White Jr, The Law and Regulation of International Space Communications, (Boston: Artech House, Inc., 1988), p. 238.

Figure 3.1. The United Nations and Related Agencies.

provides a check for this process by being able to override a majority General Assembly vote with a three-fifths majority. The UNGA has no enforcement authority, but is permitted to establish agencies to carry out its recommendations. In this manner, it has performed the task of initiating general policy for the guidance of nations in telecommunications and satellite related areas.

On 20 December 1961, the UN General Assembly specified in resolution that "international law, to include the Charter of the United Nations applies to



Source: Rita Lauria White and Harold M. White Jr, The Law and Regulation of International Space Communications, (Boston: Artech House, Inc., 1988), p. 244.

Figure 3.2. United Nations' Bodies Concerned with Outer Space. (Dotted lines represent observers.)

outer space and celestial bodies." Although this resolution had no treaty force, it was an expression of the political will of the UN member states. Hence this decision, which was later incorporated into a treaty, being an expression of majority will became a source of international outer space law. After that, it could no longer be said that outer space was a "juridical vacuum."[3] Herein lies the power of the UNGA and how it can influence GSO use and policy.

Committee on the Peaceful Use of Outer Space. COPUOS (the Committee on the Peaceful Use of Outer Space) is an organ of the General Assembly. It is an example of an agency which was established to carry out a specific UNGA recommendation. Formed in 1958, COPUOS is the focal point for international accord in the peaceful use of outer space. It is composed of a fifty-four member committee which has formulated all existing Outer Space Treaties. The responsibility of COPUOS is to discuss the state of the art and future developments in the peaceful use of outer space, to review international co-operation in this area, and to study feasible means for bringing into reality any programs which promote such cooperation. To carry out its functions the committee is assisted by two permanent subcommittees (Legal and Scientific and Technical).[4] All UN nations are obligated to ensure that government and private persons and organizations within their charge comply with all the restrictions outlined in the Outer Space Treaties.

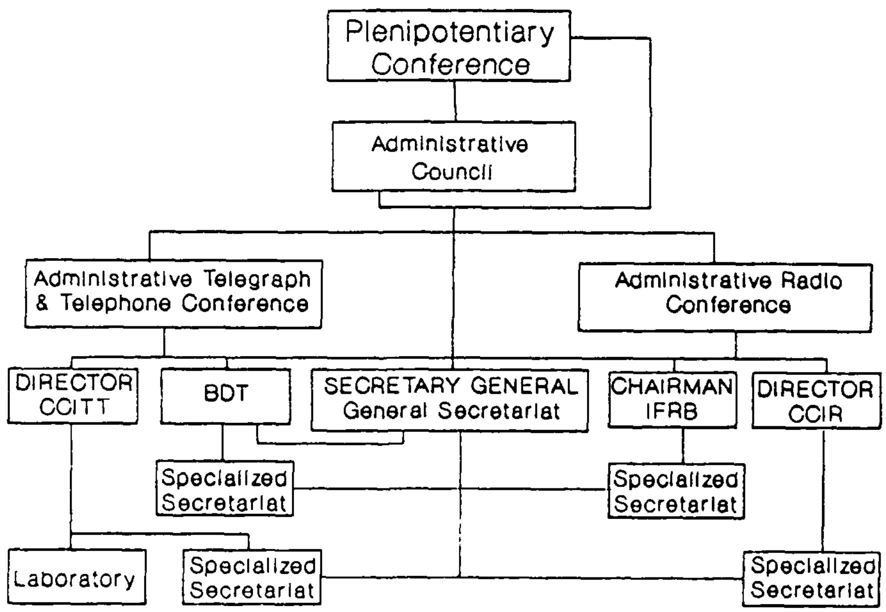
International Telecommunications Union. The most important international organization involved in satellite information networks is the ITU. It began life as the International Telegraph Union in 1865 as a means of coordinating European telegraph systems.

In 1932 it was renamed the ITU and in 1947 it became a specialized agency of the United Nations. The ITU allocates frequencies and orbital assignments so as to minimize satellite communications interference, for all of its 166 members. The ITU has no police power, with the only sanction at its disposal, for a nonconforming satellite, being to not recognize its existence. In practice, the ITU offers its services as a mediator and has a foremost record of resolving interference complaints through each nations self-interest in preventing chaos.[5]

The modern organizational structure of the ITU consists of the following four organs: The Plenipotentiary and Administrative Conferences; The Administrative Council; and The Permanent Organs. The first three could be described as Periodic Organs of the ITU, in that they are not always in session, but rather are called to meet periodically according to the procedures established in the International Telecommunications Convention. The Permanent Organs on the other hand are in continual operation, with permanent staffs, and consist of the following: The General Secretariat; The International Telegraph and Telephone Consultative Committee (CCITT); The IFRB (International Frequency Registration Board); The

International Radio Consultative Committee (CCIR); and The Telecommunications Development Bureau (BDT).[6] Figure 3.3 shows the organizational structure of the ITU, with the duties of the Periodic and Permanent Organs discussed in the following paragraphs.

The ITU's Plenipotentiary Conference is the supreme organ of the ITU and consists of ministerial-level delegates from most of the member countries. It meets every five to seven years to set the Union's agenda for the following decade (last met in Nice,



Source: George A. Codding Jr., Professor, Political Science Department, Colorado University at Boulder, Colorado.

Figure 3.3. International Telecommunications Union Organizational Structure.

France from May 23 - June 29, 1989). This Conference has both regulatory and constitutional authority, and thus it has the power to change the ITU Constitution. Between these conferences the Administrative Council, an agent of the Plenipotentiary, acts as the Board of Directors.[7] The Administrative council meets every spring in Geneva for a three to four week session and is composed of 41 members elected "with due regard to the need for equitable distribution of Council seats among the regions of the world." Presiding over the meetings, but with no voting right, is the Secretary-General.[8] It is the Councils duty to revise the ITU Convention to bring it up to date with current trends in telecommunications technology and other incidents. To supplement the Convention, the Council formulates Administrative Regulations which become binding to all upon adoption by the Union membership. They deal with such things as the use of the radio spectrum and geostationary orbit, system coordination, frequency assignment notification and registration, and other related technical matters.[9]

The procedure for revising and adopting Radio Regulations is through either a World Administrative Radio Conferences (WARC) or a Regional Administrative Radio Conferences (RARC). The Space WARC Conference

was divided into three parts. The first, considered the use of the GSO for communication satellites. The second, decided on changes that needed to be made to specified frequency bands and services. Finally, the third was used to create and establish the principles and criteria to be implemented for future frequency and orbital slot allocations.[10]

At the 1947 ITU Atlantic City Conference, the U.S. proposed to revise the "notified frequencies"[11] list, in order to reflect the actual needs of all ITU members. The IFRB was thus born, with obligations which included approving additions and changes to the frequency registry list and solving related disputes. As a result of international politics, though, it was given very little authority. It is now little more than a recorder of frequency assignments.[12]

Any party that desires a new frequency or to make major changes to an existing assignment can only do so by first notifying the IFRB. Included in items that must be reported to the Board are frequency uses capable of causing harmful interference, that are to be used for international communication, or needing of international recognition. Upon submission, the frequency assignment is examined to determine if it will cause harmful interference and if it conforms

with the provisions of the ITU's Radio Regulations. If the Board approves the assignment request, it is recorded in the Master Frequency List. If not, the assignment is returned to the submitting party. They then have the option of either finding an alternative frequency, making the necessary changes to bring it in line with the Radio Regulations, or challenging the IFRB's findings. If it can be shown that the request does not cause harmful interference, then it must be registered in the list. The Board also has the right to review assignments for actual usage and can cancel those which are not in use if the using party agrees. Although, it was never given very much power and had its size cut from eleven to five, the IFRB remains in existence because many less developed countries see the Board as a "friend in court."[13]

The CCIR and the CCITT as permanent organs of the ITU, are responsible under its Convention "... to study technical and operational questions relating to radio-communications without limit of frequency range and to issue recommendations on them...". The CCIR is more involved with GSO communications and has the following objectives: 1. to provide the technical basis for efficient use of the geostationary orbit and radio-frequency spectrum; 2. to endorse technical

arrangements and radio system performance standards that assure their effective and compatible connection and interworking in international communications.[14]

The 1989 Nice Plenipotentiary Conference saw the birth of the fifth and most recent member of the ITU, that being the BDT. Initially, its composition will consist of the staff and facilities for the past Technical Cooperation Department and until a director is elected at the next Plenipotentiary conference, it will be led by the General Secretary. The foundation of BDT will be to discharge the Union's dual role as the UN specialized agency for telecommunications and as actuating agency for execution of the projects of the United Nations Development Programme (UNDP).[15] Its responsibilities include providing assistance and advice so as to achieve greater development of world-wide telecommunications and to organize and carry-out periodic developmental conferences. This second role formalizes the informal meetings planned sporadically since the 1985 Report of the Independent Commission on World-wide Telecommunications Development.[16]

Other International Organizations

The most prominent international organization involved in GSO satellite communications is INTELSAT. Formed as an international consortium, it was given

monopoly power by its original signatories to operate and maintain a single worldwide satellite network for public international communications. Seven nations participated in the negotiations to set up INTELSAT, which by 1988 had grown to 110 members and provided two-thirds of all international telecommunications.

Initial concerns over possible U.S. system dominance were eased by an agreement which limited any countries ownership to its proportion of network usage. Rates were then set based on global averages which provided an established rate of return (set at 14% at the outset of the organization). With COMSAT as its first manager and the provider of its original satellite, the United States originally owned 61% of INTELSAT. Ownership by the U.S. has since dropped to about 25%. INTELSAT has lost some of its power and dominance in the last five years. Much of this can be attributed to pressure by private U.S. companies to ease existing monopolistic constraints on global communications.[17]

The Russians decided that instead of joining the U.S. dominated INTELSAT, they would form their own network. In 1971, the Soviet Union along with thirteen other socialist countries, including Cuba, established INTERSPUTNIK. Many other countries now

use the system, with Belgium being the only country with memberships in both INTELSAT and INTERSPUTNIK. The easing of East-West tensions, in recent years, has resulted in talks concerning the interconnection of the world's two largest international satellite telecommunications systems.[18]

In the near term, at least, it is improbable that the INTERSPUTNIK and INTELSAT organizations will merge due to their many differences. Such obstacles include: 1. INTELSAT is already a global system and would have very little to gain from a merger. 2. The Russians currently use their INTERSPUTNIK system for military traffic, and thus, would need to off-load it to other systems prior to any merger. 3. The Soviet Union is still uneasy about U.S. pull within INTELSAT and would at a minimum desire a seat on the Board of Governors, in an attempt to counter this "influence." 4. The U.S. and many Western nations are concerned that such a merger would allow Soviet access to some of their advanced technologies. Although there are numerous drawbacks to such a merger, cooperation is to everyone's benefit and could, if successful, lead to a merger within a decade or so.[19]

Another influential satellite communications organization is INMARSAT. Modeled after INTELSAT, it

was formed in 1978 (operational in 1982) to carry all maritime satellite communications (nation-to-ship and ship-to-ship), for its member nations. Ownership and usage fees are determined in a manner similar to that used by INTELSAT. In 1982 INMARSAT officially took control of satellites previously operated by MARISAT. In there early years, however, they relied on leased capacity from INTELSAT and ESA to perform their role. In 1985 they contracted to have three new INMARSAT-2 satellites built. Two of those satellites have since been launched, with the third scheduled for launch in 1990. These new satellites now represent the bulk of their operating capacity.[20]

INMARSAT is ruled by three governing bodies: the Assembly, where all member States are represented and have equal voting rights; the Council, a smaller body of the 22 largest signatories, with voting power determined by each nations investment share; and the Directorate, which is the executive body. INMARSAT provides only for the satellite communications link. Ship owners must supply the shipboard stations with the coastal Earth stations and land-line connections being the responsibility of the host countries.[21]

Overseas Telecommunications Organizations

Typically, communications in countries other than the U.S. are both provided for and regulated by a government agency usually referred to as the PTT (Post, Telephone, and Telegraph). The name is based on their roots but now their charge also includes the administration of broadcasting as well. Many PTTs are also associated with the manufacture of equipment and thus, are often reluctant to deal with foreign competitors or to promote domestic competition. The profits from their communications related activities are usually used to defray postal system expenses. The major differences between the U.S. free market and foreign monopolistic telecommunications systems, typically, results in differences arising in regard to international communications regulatory policy.

The monopolistic traditions of the PTTs have been altered in some Western countries over the last several years. In the United Kingdom, post office functions have been split off from British Telecom, which is now more than 50% privately owned. Japan is trying private ownership for both its international and domestic telephone systems. The EEC's Treaty of Rome discouraged competitive constraints among member countries, on all products and services, to include

telecommunications. In general though, there is no world-wide move towards deregulation. For the U.S., fast international agreements are usually only viable when dealing with the few nations that have COMSAT type organizations which are dedicated to satellite network operations. These include: Canada (TELSAT), Japan (NASDA), Italy (TELESPAZIO), and India (Indian Space Research Organization, ISRO).[22]

Another category of foreign organizations gaining popularity and strength around the globe are the many multinational satellite organizations which have formed in the last ten years. Examples include ARABSAT (Arab Satellite Communications Organization), ARSC (African Remote Sensing Council), and EUTELSAT (European Telecommunications Satellite Organization). All of these organizations presently have over twenty signatories which makes them a legitimate forces when it comes to block voting within the ITU.

The last major overseas telecommunications satellite organizations to be discussed is the ESA (European Space Agency). It was formed in 1975 with the merger of the nearly dormant European Scientific Research Organization and European Launch Development Organization (ESRO and ELDO). ESA is composed of the thirteen European Economic Community (EEC) members,

Luxembourg is not a member, and has technical accords with Canada. Funding for the ESA is provided by the member states, with finances for mandatory activities based on national income and contributions for other programs negotiated based on the level of involvement of member nations. ESA's most important activity is as the sponsor of the Arianespace commercial launch program. Additionally important is that they are the only space organizations which is a signatory to the United Nations Space Treaties.[23]

United States

Regulation of communications services in the U.S. is provided for by the 1934 Communications Act. Satellite communications is covered in 1962 Satellite Communications amendment to the 1934 Act. It states that the Executive branch and the FCC are to be the primary administrators, with additional duties being performed by NASA and COMSAT. The responsibilities of each of these organizations will be detailed in the following section.

The Executive Branch. The 1962 Satellite Act recognizes the foreign policy, national security, and trade aspects of international communications by way of satellite. It states that it is the President's

duty to determine whether additional international satellite systems are required to meet governmental needs or are required in the national interest. The "national interest" includes such factors as general competitive policy, promotion of U.S. international trade in goods and services, furtherance of overall U.S. spectrum management goals, the advancement of technological progress and innovation, and expansion of international communication options available to the U.S. business community.[24]

The Executive Branch's foreign policy role is typically delegated to the State Department. In his September 1983 letter to Chairman Charles H. Percy of the Foreign Relations Committee, Secretary of State George P. Shultz emphasized the basic international satellite communications foreign policy objectives of the United States.

> "To promote an environment in which ideas and information can flow freely among nations, to support the advancement of international commerce through the efficient and innovative use of communications resources, and to expand the information access and communications capabilities of developing countries."[25]

The Department of Defense fills the national security role of the Executive branch. As mentioned in Chapter II, as many as one-third of all satellites launched in the United States have a military related

function. The DoD must ensure that neither domestic nor international regulatory policy interferes with its ability to perform its national security duties. In addition, with the large contingent of Soviet and other potentially adversarial satellites parked in the geostationary orbit, it is their responsibility to ensure that the activities of these spacecraft do not in any way endanger the people or the peaceful activities of the United States.

The trade aspects of satellite communications are filled by the Commerce Department. They have two major divisions which are actively involved in policy and regulatory decisions. NOAA has its contingent of meteorological satellites and is interested in any communications policy decision which might hinder it in the performance of its duties. The NTIA (National Telecommunications and Information Administration), formed in 1978, is responsible for development, use, and regulation of telecommunications and information services. It acts as the President's chief advisor on telecommunications policy matters. In addition, their Interdepartmental Radio Advisory Committee, IRAC, is responsible for the proper allocation of government spectrum. NTIA has a limited policy making role with virtually no enforcement power.

Federal Communications Commission. The FCC is the U.S. agency responsible for administering the regulatory and legal aspects of all communications services. With respect to satellite communications, early in 1970 the FCC started to accept applications for the establishment and operation of U.S. domestic satellite systems. Its Second Report and Order was issued in 1972, marking the beginning of the "open skies" era. Under this policy, all technically, financially, and legally qualified applicants were authorized to provide approved satellite services. FCC satellite related duties include: authorizing the establishment and operation of a communications satellite channel; assignment of orbital positions for all U.S. geostationary communications related spacecraft; and regulation of satellite spacing.[26]

NASA. The National Aeronautics and Space Administration is a United States Government agency which is well known for its role in all aspects of space related exploration and research. Formed in 1958 by the National Aeronautics and Space Act, its functions as conceived were to plan, direct, and conduct all U.S aeronautical and space activities except those that are primarily military in nature. In recent years, NASA has become more actively

involved in military related space missions, and is thus involved in the formulation of all satellite communications policy.

COMSAT. The 1962 Communications Satellite Act addressed international satellite communications. It resulted in the creation of the Communications Satellite Corporation which was the only authorized agent to represent the United States interests in the international consortium, INTELSAT. COMSAT, in addition to being the U.S. signatory to INTELSAT, was also the original manager of the organization as well as the main technical and operating arm.[27] In the 1960s and 1970s, COMSAT was actively involved in the creation of both international and domestic satellite policy. Since the deregulation of the communications satellite industry in the U.S., it has been levied to just one of many players trying to influence changes in U.S. satellite policy, but still holds some of its former status in the international community.

Regulatory Conferences

Regulatory Conferences are the select way of politicians for resolving the World's most difficult problems. Typically representatives from any and all affected parties get together at a pre-assigned time

and location, with a goal of compromising on their differences. The problem with this procedure is that concerned parties have at least slight differences in their policies and agendas, and often these views and goals are diametrically opposed. It is the nature of these proceedings that every group will attempt to hold to their values as long as possible in the hope that any final resolution will contain more of their goals than of their oppositions. Consequently, these conferences are often long and drawn out with much of the work accomplished in the wanning hours when it is feared that the conference is about to disintegrate. In typical compromise fashion, the final resolutions are unsatisfactory to all parties and in the opinion of this observer, are often not in the best interest of the world as a whole.

The development of GSO communications policy and regulation through its history has been slowed by two major problems: 1. the conflict between policy institutions and technological development and 2. the differences between international and domestic policy and regulation. "Fundamentally, the development and use of the geostationary orbit has been a classic struggle between technology and policy at both the international and domestic level."[28] In the previous

section the organizations responsible for undertaking these struggles were addressed. Presented here will be the most significant regional and world-wide GSO policy struggles.

The first two decades of satellite communications saw the United States as both the policy development and technology leader. In the third decade and today at the beginning of the fourth, other influences have started to dominate. These include developing world demands, which are dramatically altering the course and direction of GSO technological development and regulation, and the loss by the U.S. of its status as the World's premier technological power.

Pre 1979 Activity

The ITU's first involvement in communications via satellite was the Administrative Radio Conference of 1959, convened to review and revise existing Radio Regulations. The successful USSR launch of SPUTNIK-1 two years earlier made the subject of communications by satellite a hot conference discussion topic. In response the upper limits of the Frequency Allocation Table were extended and the frequency band from .136 to 31.8 GHz was assigned for space research purposes. Realizing that satellite radio services were too new

to plan, they decided to consider the needs of space communications services at a later conference.[29]

Serving this function was the resulting 1963 Extraordinary Administrative Radio Conference. Its actions included revision of the Frequency Allocation Table and recognition of new satellite services such as meteorological. The table was changed to include both the new services and the rapidly expanding older satellite services. Nearly 2,800 MHz of spectrum was allocated to satellite communications on a shared or exclusive basis. Setting the foundation for future equitable access battles was the conference's ruling that satellite communications radio frequencies were to be assigned on a first-come, first-serve basis in a manner similar to what was then customary for most terrestrial services. Developing nations' pleas for global satellite communications organization, which they argued would allow access and benefit for every nation, were denied. The contention of Third World nations being that left unregulated, communication by satellite would be monopolized by richer nations.[30]

The Outer Space Treaty (OST) became operative in 1967. It states that "no part of space is subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means."

In other words, a nation cannot own an orbit. Claims of GSO ownership, by equatorial countries, in later years would result in heated debate over this issue. The Outer Space Treaty also states that interference with another's peaceful activities in outer space is forbidden, thus satellite systems in place can not be tampered with. This treaty also places international liability on governments for all national outer space activity, whether or not the government entities were actually responsible for carrying them out.[31]

The third major ITU conference involved with satellite communications was the World Administrative Radio Conference on Space Telecommunications in 1971. This conference primarily dealt with technical issues such as developing a criteria for distinction between space and terrestrial services, and initiating usable guides for pointing accuracy, acceptable interference levels, frequency sharing between space systems, and station keeping. Once again the Frequency Allocation Tables were revised to accommodate the rapid increase in satellite related services. Added was 177 GHz of frequency spectrum to be shared among terrestrial and satellite services.[32] Again, the developing nations expressed concern over the allocation method used to assign orbital slots and transmission frequencies.

To appease them, the following resolution was enacted.

> "All countries have equal rights in the use of both the radio frequencies allocated to various space radiocommunication services and that registration with the ITU of frequency assignments for space radiocommunication services and their use should not provide any permanent priority for any individual country or group of countries and will not create an obstacle to the establishment of space systems by other countries."[33]

It was agreed, though, that the allocation system in use would continue but the issue would be considered again at a future conference. The establishment of the broadcast satellite service was another area that stirred the conference. Controversy centered around the use of broadcast satellites and how to prevent the direct broadcasting of signals from one country to another unwilling country. The argument was that it represented an invasion of a nation's sovereignty and could pose a threat to its culture.

The ITU's Malaga-Torremolinos Plenipotentiary Conference of 1973 produced three important satellite related happenings. First, it laid the ground-work for the 1977 Broadcast Satellite Conference. Second, it gave the IFRB added GSO position related duties. Third and most importantly, it sided with developing nations concerning the assignment of geostationary satellite orbital positions and frequencies. This

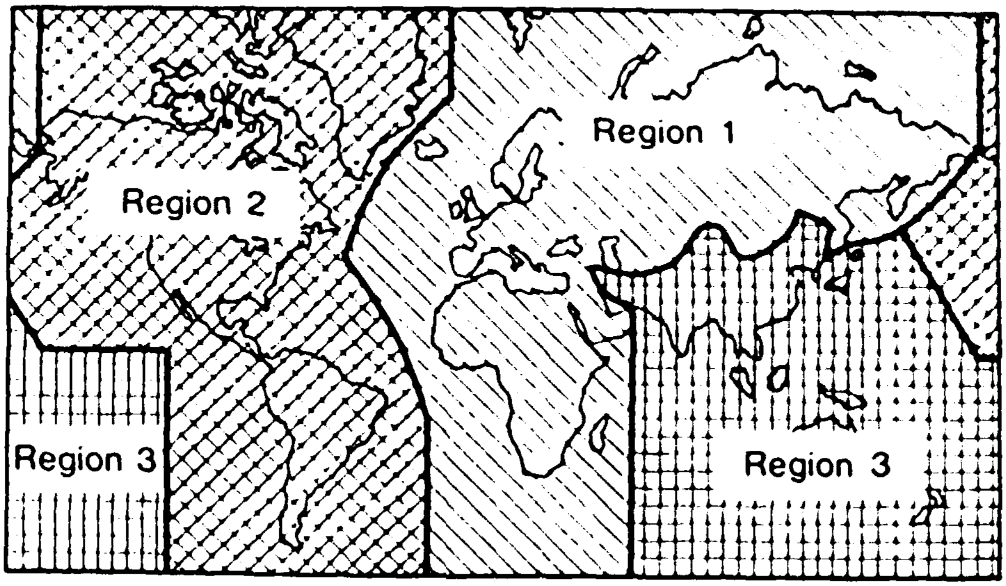
resulted in the addition of the following paragraph as Article 33, and titled "Rational Use of the Radio Frequency Spectrum and of the Geostationary Satellite Orbit," to the ITU Convention.

> "In using frequency bands for space radio service members shall bear in mind that radio frequencies and the geostationary satellite orbit are limited natural resources, that they must be used efficiently and economically so that countries or groups of countries may have equitable access to both in conformity with the provisions of the Radio Regulations according to their needs and the technical facilities at their disposal."[34]

The lines were now in place for the battle that would be waged for the next fifteen plus years.

The 1977 Broadcasting Satellite Conference decided that meeting the goal of equitable access to the 12 GHz broadcast satellite service could only be obtained by establishing a rigid long term "a priori" plan. It was decided that each ITU member would be allocated a portion of the GSO and the frequencies necessary for broadcasting, regardless of its needs or ability to use them. The conference then drew up an allotment plan for Regions 1 (Europe, Africa, the Middle East, the USSR, and Mongolia) and 3 (Asia, and the Pacific Basin other than Hawaii) based on factors such as orbital position, assigned frequencies, area of coverage, equivalent isotropically radiated power, polarization, antenna beamwidth, ellipse orientation,

and bore sight coordinates. Figure 3.5 depicts the three ITU regions and the World area covered by each. Largely because of U.S. insistence, it was agreed to postpone the creation of an "a priori" allotment plan for Region 2 (North and South America, the Caribbean, and Greenland).[35] The Regional Administrative Radio Conference which resulted in 1983, will be discussed in a later section.



Source: Geoffrey E. Lewis, Communications Services Via Satellite, (Oxford: BSP Professional Books, 1988), p. 5.

Figure 3.4. Regions of the International Telecommunications Union

Space WARC-1979

Convening in Geneva, Switzerland on the 24th of September 1979, Space WARC-1979 lasted 11 weeks, ending on December 6th. The 2000 delegates from 150 countries set out to devise an orderly and rational system of radio frequency allocation. The conference covered all areas of space communications but for the sake of brevity, discussion in this here will focus on geostationary satellite communication. Agreements were reached on greater interference allowances and on improved station keeping standards. Surprisingly, there were only two areas where delegates were unable to generate acceptable solutions. Of importance here is the now age old dispute of "a priori" planning of transmission frequencies and orbital slot positions for fixed service and direct broadcasting satellites operating in the GSO. Important fuel to the Third World fire was a NASA study which predicted that the demand for the geostationary orbit would increase ten fold over the years 1982 to 2000. This increased the fears that there would be no orbital slots available for them in the GSO.[36]

The result was an increase in the undeveloped nations' demand for "a priori" planning, in an effort to save some of the remaining desirable GSO slots for

themselves. They argued that these positions should be "reserved" until they had the technology and the finances to place a communications satellite of their own into orbit. Listed as precedence for this demand were the Final Acts of the 1977 Broadcast Satellite Conference. In contrast the industrialized nations felt that it was in the best interest of all nations to maintain the then present first-come, first-serve assignment system. They argued that technology would make additional slots available before these nations were ready to place satellites into orbit. Unable to reach an acceptable compromise, the delegates agreed to hold a two stage geostationary satellite planning conference, to convene in 1984 and 1986 (met in 1985 and 1988). The functions of these conferences were spelled out in Resolution 3 of the conference's Final Acts. The stated purpose of the first meeting was to decide which services and frequency bands were to be planned and then establish the principles, technical parameters, and planning criteria. Actual allotments were to be made at the follow-on conference.[37]

This assignment process was to be restricted to the additional 1600 MHz of frequency (800 MHz for both uplink and downlink), made available for space communications, by the conference. Commonly known as

the extension bands, it included 600 MHz in the "C" band (6.725-7.025 GHz for uplink and 4.5-4.8 GHz for downlink) and 1000 MHz in the "Ku" band (12.75-13.25 GHz for uplink and 10.7-10.95 GHz and 11.2-11.45 GHz for downlink.[38] The affected "Ku" band frequencies were not determined until after the 1979 WARC.

Intersessional Activity I (1979-1985)

The ITU's Nairobi, Kenya Plenipotentiary Conference of 1982 again modified the direction of GSO use when it changed Article 33 of the Convention by adding the following: "Members shall endeavor to limit the number of frequencies and the spectrum used to the minimum essential to provide in a satisfactory manner the necessary services. ... they shall [also] endeavor to apply the latest technical advances as soon as possible." In addition the original text of Article 33, quoted in a previous section, was changed to give extra consideration to the "special needs of developing countries regardless of the technical facilities at their disposal."[39]

A Regional Administrative Radio Conference (RARC) was held in 1983 to plan the satellite direct broadcasting services for Region 2. It succeeded in drafting a mutually agreeable allotment plan that the participating nations felt was more flexible and more

appropriate for proposed services than the rigid plan framed by the 1977 Broadcasting Satellite Conference. The largest share of frequency channels and orbital slots were allocated to the U.S. (256 channels and 8 of 48 orbital slots). The 1983 plan also included two slots for services shared by groups of nations.[40]

The CCIR was directed by the 1979 Space WARC to carry out studies to provide technical information for the 1985 Conference. The IFRB was also directed to provide technical input to ORB-85. IFRB studies were requested primarily by developing nations that felt CCIR technical studies would favor the position of developed nations. The rational for this position being that developed nations were more apt to attend CCIR meetings because they are more prone to have the financial and technical means to do so. Thus, the IFRB and not the CCIR is more likely to favor the "a priori" position of developing nations. The ORB-85 Conference Preparatory Meeting of the CCIR were held in 1984 and produced seven proposals for regulation of space communications. Each proposal presented an alternative GSO planning approach. Five approaches were developed by the CCIR working parties in 1983-84 while the other two were submitted for consideration by the USSR and China.[41]

GSO regulation was also a topic of discussion at the 1980 CCIR interim working party of Study Group 4 (IWP 4/1), and the UN's Second Conference on the Peaceful Use of Outer Space (UNISPACE '82). Detailed results of the various intersessional meetings is not needed for subsequent discussion and thus will not be presented. Curious readers may consult references if more information is desired. Two observations that can be made about the six year period between WARCs are 1. supporters of both sides of this issue relied heavily on political maneuvering, trying to gain an edge going into the ORB Conference and 2. none of the studies seemed to have an impact on the ORB outcome. As will be seen in the next section, ORB(1) seemed to ignore the technical studies and followed the typical regulatory conferences scenario presented earlier.

Space WARC ORB-85

The 1985 Orbit Conference (ORB(1) or ORB-85) convened on 8 August 1985 in Geneva. In attendance were over 1000 delegates from 140 ITU member nations. Their principle goal was to define the ground rules for access to the geostationary satellite orbit. The conference's primary focus was fixed satellites, with final recommendations to be implemented by the second ORB conference in 1988. To the surprise of many, the

developed and undeveloped countries of the world were able to come to agreement on a GSO slot and frequency allocation process. The agreement was reached in the last couple of days when many felt the conference was doomed to end with no final resolution. Concluding resolutions were hashed out in marathon eighteen hour sessions that pushed the conference several days past its scheduled completion date. Concluding on the 15 September, the conference succeeded in accomplishing most of what it set out to achieve and by regulatory standards could be deemed at least a semisuccess.[42]

The final resolution consisted of a two part allotment plan. Part one required that a bandwidth of at least 800 MHz (for both uplink and downlink), in two transmission bands ("C" and "Ku"), be reserved for every nation, with the actual assignments to be defined at ORB-88. Scheduled to be allotted were the "C" and "Ku" extension bands as defined by the 1979 Space WARC. Exempted from the orbital arc allotment plan was the 30/20 GHz "Ka" band because of its then experimental nature. Part two of the allotment plan called for development of an improved procedure for assigning all unreserved frequency bands and orbital slots. It was decided that these allotments would be assigned by a multilateral planning meeting. These

meetings, which were to convene periodically, would evaluate all applications and parcel out unreserved orbital slots based on factors such as need, general good, national welfare, and first-come.[43]

One major problem faced was how to deal with orbital slots which were already being used or were scheduled for use by a satellite under construction. Undeveloped countries wanted to force developed ones to abandon the most commonly used lower frequency bands. It was felt that the developed nations were more financially and technically able to operate in the higher frequency bands. In the end this proposal was defeated and all nations were given equal access to all frequency bands. In addition, most existing satellites were allowed to maintain normal operation, with their orbital positions to become part of the unreserved pool when freed from use.

Two other important ORB(1) happenings were recognition of the needs and roles of multinational organizations such as INTELSAT and the GSO ownership claims of the equatorial countries. The recognition of the many multinational satellite organizations led to their inclusion in the GSO planning scheme. They, however, were not given priority as they desired. In the opinion of many private U.S. satellite companies,

this represented an open invitation for competition. This ruling is still significant in that often these organizations represent the only source of satellite communications that many countries will ever be able to afford. Columbia argued that they and all of the other equatorial countries have claim to sovereignty over parts of the GSO that pass over their territory. Most ITU members disagreed and the claim was dropped before coming to a vote.

The general consensus was that almost every nation got something positive from ORB(1) but that no one was totally pleased. These words from Noureddine Bouhired, director of the Algerian delegation and one of the most vocal spokespersons for the rights of the developing countries, tends to prove this very point. "I find the compromise very equitable, and the proof of this is that everyone is equally dissatisfied."[44]

Intersessional Activity II (1985-1988)

This intersessional period was dominated by intense activity on the part of individual nation's administrations, the General Secretariat, the IFRB, and the CCIR. Most of this work was assigned by the first ORB conference in preparation for ORB(2). The individual administrations, typically, met frequently to plan their strategies for the conference while the

General Secretariat had all the responsibilities of planning and organizing the conference's activities.

The IFRB was tasked to perform several major duties during this period. Its primary obligation was to develop a software program to be used in the preparation of the allotment plan, and to carry out appropriate planning exercises. Because of limits on IFRB time, finances, and manpower, this development effort primarily fell to member nations, most notably France, Switzerland, Japan, and the U.S. The IFRB was also delegated other tasks to include: reviewing the sharing criteria for satellite and terrestrial services; aiding in the development of guidelines for regulatory procedures related to the planning method; and performing duties associated with the planning of the broadcasting satellite feeder links in Regions 1 and 3. This last charge included the assignments of adapting computer software for feeder link planning exercises and performing the exercises. In addition, the IFRB was ordered to review the Master Frequency Register, the International Frequency List, and other such documents to make sure that they were accurate and current. The updated records were necessary to allow the ORB-88 conference to carry out its work.[45]

ORB(1) also identified intersessional studies to be carried out by the CCIR for use as technical support to ORB(2). The CCIR's XVIth Plenary Assembly devised the guidelines and organized these committees to carry out the intersessional work: Study Group 1-Spectrum utilization and monitoring; 2-Space research and radioastronomy; 4-Fixed-satellites; 5-Propagation in non-ionized media; 8-Mobile, radio-determination and amateur services; 9-Fixed satellite service using radio-relay systems; 10-Broadcasting services-sound; and 11-Broadcasting service-television. In addition, Interim Working Parties (4/1-Technical considerations affecting the efficient usage of the geostationary-satellite orbit and 8/7-technical characteristics of systems in the maritime mobile-satellite service) and other related Joint Interim Working Parties were held to study specific issues.[46] Details of these studies that relate to technical alternatives to orbital slot allocation will be presented in Chapter IV.

Space WARC ORB-88

Meeting from 29 August to 6 October 1988, the task of ORB-88 was to translate the principles laid out in ORB(1) into specific Fixed Satellite Service allotments for all ITU members. It was attended by 937 delegates from 120 countries plus representatives from 15 regional and international organizations. Of concern were the 1600 MHz of expansion frequencies made available by Space WARC, 1979. As it turned out equitable access did not result in equal amounts of spectrum for every nation. The justification being that some countries, notably the industrialized ones, have more requirements for satellite communications, than do others, such as those of the Third World.[47] Any other solution could have yielded a potentially chaotic world-wide satellite communication situation due to noncompliance by industrialized nations.

The problem of what to do with the existing satellite systems was handled by giving them 20 years of tenancy at which time the remainder of the orbits and frequencies were to be planned. What equitable access resulted in was the allotment of at least one orbital slot (large countries were given more), with access to 800 MHz of spectrum for uplink and downlink transmission (300 in "C" and 500 MHz in "Ku" band),

and a protection ratio against interference (Carrier power/aggregate interference power) of 26dB to every member of the ITU, nearly every nation in the world. The parceling out of the "reserved" orbital slots was performed by the Japanese developed computer program, Orbit-2. American delegates wanted to use the NASA developed NASARC program because it was more flexible in its allotments. ITU experts ran the NASA program but chose instead to stay with the Orbit-2 program.[48] The Orbit-2 program was not always successful and the its results often had to be manually manipulated to obtain the desired results.

To allow for planning flexibility, each slot was to be treated as a nominal pre-determined orbital arc with a possible range of $\pm 10^{\circ}$ at the system pre-design stage, $\pm 5^{\circ}$ at the design stage, and 0° at the operational stage. Technical parameters used in the planning included C/N ratios of 23dB for uplink, 17dB for downlink, and 16dB overall in rainy conditions. Minimum beam sizes were set at 1.6° for "C" band and 0.8° for "Ku" band, while the satellite antenna beam pointing accuracy was mandated at $\pm 0.1^{\circ}$. If requests for allotments were not submitted, then the IFRB made the assignments. The final plan also had provisions for groups of countries to establish a sub-regional

satellite communications system. In such a case all participating national allotments would be suspended for the lifetime of the sub-regional scheme but still protected for later use.[49] With few exceptions, all nations received an allotment which met the minimum established requirements.

As for direct broadcasting from the GSO, the main task of the ORB-88 conference was to establish a feeder link for BSS (Broadcast Satellite Service) in Regions 1 and 3. It was successfully established in the 17.3-18.1 GHz band. The maximum additional power increase for BSS in heavy rain was also established at 10dB. Activity on digital sound broadcasting was deferred to a future conference and there was little progress in trying to set-up a world-wide allocation for wideband HDTV systems. And finally, frequency allocations to the mobile satellite services were modified to provide spectrum specifically for land mobile applications.[50]

ORB-88 seemed to be more in line with the ITU conferences of the past when technical answers seemed to provide the solutions to the world's communication problems. From an outside point of view, it appeared to be somewhat void of the typical gamesmanship toyed with by the delegates of previous conferences. From

both a fixed and broadcasting satellite stand point, ORB-88, in this observers view, was a success.

Post ORB-88 Activity

The 13th Plenipotentiary Conference held from 23 May to 29 June 1989 in Nice, France was uneventful as far as geostationary satellites were concerned and when compared to the previous year's WARC. What the conference did accomplish was to establish the ITU's future direction in all areas. What this meant for satellite communications was that it remained nearly unchanged. Of significance to the satellite world was the proposal for a Mobile Satellite WARC in 1992. Included in the WARC will be a session designed to find a band for satellite sound broadcasting service within the 500-3000 MHz range.[51]

NOTES-CHAPTER III

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CHAPTER IV

TECHNICAL SOLUTIONS

It is argued, by many experts, that technical advances will eventually eliminate the GSO crowding problem. This will be possible because of an overall increase in satellite communications capacity. There are generally two alternatives for accomplishing this task. First, is to increase the number of satellites that can effectively serve communications purposes. Second, is to increase the communications capacity of individual orbital positions. These goals can often be accomplished in various ways and thus, discussion in this chapter will focus on working level technical solutions and not broad goals. Further, it should be obvious that different options may be best suited for different regions and a combination of solutions may ultimately produce the best results.

A greater number of communications satellites can be provided for in two basic ways. First, is to increase the number of different orbits that can be used for communications. Ways of doing this include using other geostationary type orbits, geosynchronous

orbits, and low orbit multisatellite systems in cases where 24-hour communication is needed. Networks that require only part-day service can use lower orbiting satellite systems that provide the needed operational capabilities. 24-hour communications service, in the future, may be provided through the use of low Earth geostationary satellites. Increasing the number of spacecraft that can communicate from a given orbit, especially the GSO, is a second method of increasing the total of usable communications satellites. Since existing station keeping technology is not a limiting factor, the answer is to improve communication system capabilities and practices for reducing interference. Antenna design advancements, such as decreasing side lobe size and increasing pointing accuracy, are areas that will increase communication system capabilities. Methods for increasing orbital capacity are satellite communications techniques such as multiple access and modulation techniques, signal polarization, frequency spreading, and advanced antenna designs; and enhanced coordination techniques such as reverse bandworking, frequency segregation, and orbit sectorization; and other techniques like using higher and more spectrum and intersatellite links.

Increasing the communication capability of an orbital position can be accomplished in three general ways. First, geostationary satellites must be fully utilized. An effort must be made to use the existing underutilized transponder capacity before efforts are made to launch additional satellites. Second, is to increase the number of spacecraft which can occupy a nominal satellite position. Using satellite clusters will accomplish this goal. Third, is to increase the capability of communications spacecraft. Many of the same techniques used to increase orbital capacity can also be use to increase the communication capacity of an individual satellite. Such methods include signal polarization; compression, modulation, coding, and multiple access techniques; and spectral separation. Future option may include multipurpose satellites and space platforms.

Increased Satellite Capability and Utilization

Great strides have been made over the past 25 years to increase the capabilities of communications satellites. A prime example can be seen in examining the evolution of the INTELSAT system from Early Bird to INTELSAT 6. The system has seen a 7,000% increase in bandwidth and a 5,500% increase in power, with the

result being a 17,000% increase in total capacity of the global communication system. Increased satellite capacity is the result of advances in antenna design, use of increasingly higher frequencies, and multiple access and modulation techniques. All of these areas will be covered in detail by later sections of this chapter. The combination of these advances not only provides more operational frequencies but also allows their reuse up to six times. Future systems may be able to provide frequency reuse up to twenty times or more.[1]

Power system and electronic advances also add to this rapid growth. Increased power generation and storage capabilities as well as reductions in power consumption per communications capability are but a few of the power system advances. Gains in this area include the enhanced battery and solar cells listed in the Power Generation and Conditioning section of Chapter II. Electronic advances have led to solid state amplifiers and monolithic devices which allow spacecraft to be lower in mass, higher in efficiency, and much more reliable in performance.[2] It would be difficult for future space capabilities to advance as rapidly as they have in the past. Even modest gains, however, will significantly increase total satellite

communications capacity. Efficiently used this added capacity can greatly enhance the world communications situation and assist in reducing GSO crowding.

Added capacity must not be allowed to amplify the existing problem of transponder underutilization. According to the 1987 FCC report titled "Transponder Occupancy Data Report," based on a spot check of U.S. satellites, nearly one third of all transponders are idle. Surveying over 500 transponders on 25 active U.S. domestic communication satellites, the FCC found that only one-third were fully utilized. The other transponders were either used on a part time basis or carried no traffic at all. Important to note is that it is very common for two transponders per satellite to be maintained in reserve as spares. Excluding two spares per satellite, this still leaves idle capacity at between 20 and 30 percent. The irony is that with all of this excess capacity, twenty-two new domestic satellites were granted launch authorization for the period 1988-1997.[3]

Efforts must be taken to reduce transponder underutilization. Recognizing the growing shortage of spectrum and GSO orbital slots, it is essential that available frequencies and transponders be used to the fullest possible extent, not only in the U.S.

but around the world. If a user, whether a company or a country, can not fully utilize a satellite or a single transponder, then plans must be made to share the unused portion of the resource with another user. To accomplish this, users must be willing to place differences aside and either compromise on a shared system or conform requirements to fill an existing underutilized system. After all such alternatives have been exhausted, then and only then should the authorization for new systems be granted. A formula such as this makes sense from both an economic and a crowding perspective. Full utilization of existing and planned resources should be the backbone of any plan (technical, regulatory, or market) for easing the GSO crowding problem.

Nongeostationary Communication Satellites

The first purely technical means to overcome the natural limits of the geostationary orbit is to move to other orbits. There are several alternative orbits which can be used for communications purposes. The individual requirements of each satellite system will dictate which if any of these alternative orbits can be utilized by a particular system.

Highly elliptical orbits have been used by the USSR for communication since 1965 and, of course, are very well known. What is not well known is that now Western European researchers are starting to also consider them. A few facts on the familiar Molniya orbit will aid in this discussion. They are at high angles of inclination (63.4^{o}), are not geostationary, and are mainly restricted to regions centered below apogee. Apogee is about 40,000 km above the Soviet Union while perigee is only 500 km above the Earth's southern hemisphere. A Molniya satellite's orbit is 12-hours, thus each spacecraft appears above a given place at the same time every day, but of course it has to be tracked by the earth station as it passes overhead. Each satellite is visible for only about 8-hours over the service area. At least three are needed to provide 24-hour coverage (4 are typically used, spaced at intervals of 90^{o} or 6-hours).[4]

The principle advantage of this type of orbit is that, for northern regions, the satellite appears directly overhead. Thus, earth station antennas are pointed upward at a high angle of elevation. Line of sight is direct with no solid obstacles and a minimum of atmosphere to pass through. In contrast, GSO use requires northerly regions to utilize low elevation

angles, with signals traveling long distances through the atmosphere. The result is conflict with man-made and natural obstacles, interference from terrestrial communications, and propagation distortions. These obstacles are especially annoying for mobile systems. For this reason, the European Space Agency is looking very seriously at elliptical orbits for land mobile radio and sound broadcasting.[5] These orbits could be used to meet other communications needs should demand dictate, particularly in Region 1 where a major part of the population lies in northern regions.

Some recent attention has focused on orbits which are geosynchronous but inclined at an angle of a few degrees to the equatorial plane and thus do not allow satellites to be geostationary. Geosynchronous satellites occupy fixed mean longitude positions but vary in latitudinal position. Such orbits allow the effective use of the same longitude and spectrum by several satellites. It is necessary for satellites in both geostationary and quasistationary orbits to have proper angularly separated phasing. If out of phase in relation to each other, mutual interference will result due of the close proximity of orbits.[6]

Best service is given by synchronous orbits which have low inclination angles (high inclination

Satellites occupy three orbital planes which are angularly spaced 120^{o} from each other. Orbital elements are selected so that satellites follow each other in the coordinate system that rotates with the Earth. This arrangement results in two small loops, 180^{o} apart, positioned above particular points on the surface. Observers on Earth would see a satellite in each loop, circling it in eight hours. A satellite would be in each loop at all times: as one satellite leaves, the next satellite in the sequence enters the loop. Table 4.1 specifies the orbital parameters of the three elliptical orbits. One proposed version of

Table 4.1. LOOPUS Orbit Parameters

PARAMETERS	VALUE	UNITS
Period	11.963	h
Semi-major axis	26,585.7	km
Eccentricity	0.7132	
Inclination	63.4	^{o}
Perigee radius	7,618	km
Perigee altitude	1,238	km
Apogee radius	45,497	km
Apogee altitude	39,117	km
Argument of perigee	90.0	^{o}

Source: Tom Ivall, "Geostationary Loops?" Electronics & Wireless World, September 1988, p. 903.

the LOOPUS system would produce geostationary loops above Europe at 10^{o}E and above the Pacific Ocean at 170^{o}W. Both loops would be at latitudes between 45^{o}N

angles reduce the 24-hour service area of a single satellite. The major limitation of such an orbit is that substantially more complex and costly space and ground segments are required in relation to what is needed for a standard geostationary satellite system. Much of this is attributable to tracking equipment[7] necessary to maintain communications. Though viable for most communication purposes, the high operational cost of geosynchronous satellite systems will prevent their commercial utilization until saturation of the GSO or directive so dictate.

Geostationary type systems which use orbits other than the traditional GSO are being considered as alternatives for reducing the orbital crowding problem. One such system uses three satellites in different elliptical paths. Instead of producing the traditional fixed point in space, they create a small narrow geostationary loop, which is always occupied by a spacecraft. This project is the joint work of three West German organizations: the communications company ANT Nachrichtentechnik, the aerospace company MBB/ERNO, and West Germany's aerospace research and development body DFVLR. They have named their system LOOPUS for, geostationary Loops in Orbit OccuPied by Unstationary Satellites.[8]

and 63.4°N.[9] Figure 4.1 shows what such a satellite system would look like. In (a), the three elliptical orbits are shown as seen from a fixed position. (b), shows the satellite track as seen from within a frame of coordinates rotating with the Earth. A matching, independent, upside down system could be used to give good coverage in the southern hemisphere. Apart from relieving the current GSO congestion problem, LOOPUS would also provide two other benefits. It would give

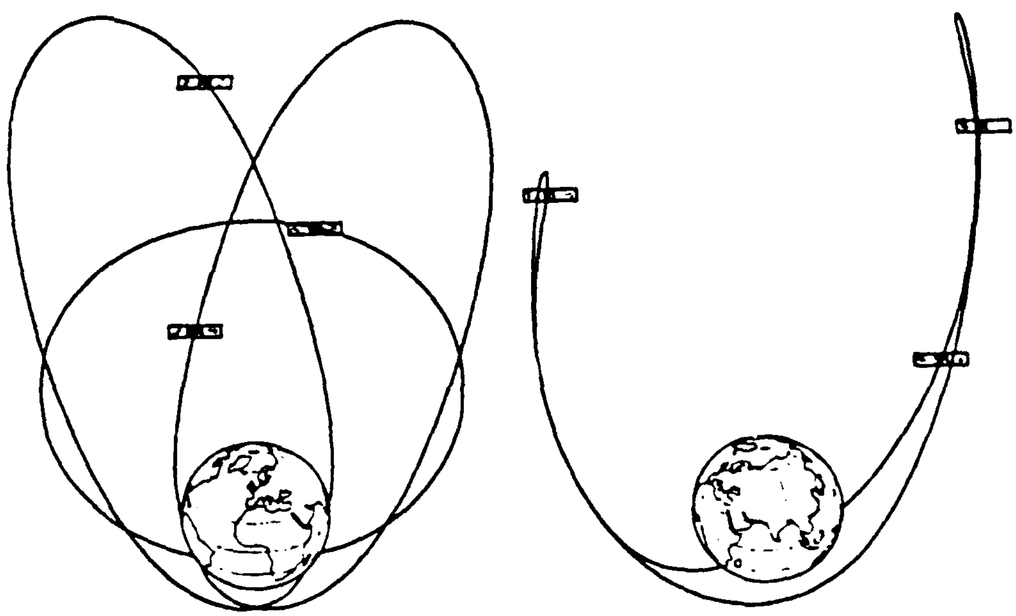


Figure 4.1. LOOPUS Satellite System

Source: Tom Ivall, "Geostationary Loops?" Electronics & Wireless World, September 1988, p. 903.

better coverage of polar regions than does the GSO and would allow single-hop connections between earth stations on opposite sides of the world provided they were in the same hemisphere.[10]

One problem that was considered in devising the LOOPUS system was the changing coverage area[11]. It was originally assumed that the varying distances and angles of the spacecraft relative to a point on Earth, as the satellite moves around its loop, would greatly alter the coverage area shape. A study has shown, to the contrary, that by taking the PFD as a basis for determining the edge of the coverage area, the changes in path attenuation are compensated for by changes in the satellite antenna gain which affect the edges of the coverage area. Thus, the coverage area remains nearly constant, with minor deformations occurring as a result of changes in the satellite's angle relative to the Earth. Another problem is that the parameters of the ground-to-space radio link are affected by the varying position of each satellite as it travels around the geostationary loop. Techniques must, thus, be introduced to overcome Doppler effect induced changes in received carrier frequency and the hand off every eight hours of the communications task to the next satellite.[12]

A further satellite communication possibility may be the use of nongeostationary orbits. Networks that require 24-hour coverage could three satellites with greater than 8-hour periods. For networks which do not need 24-hour service, a single spacecraft with a period of 12-hours or less may be used. One orbit which can fill either situation is the Ford Aerospace Corporation recommended STET (Sun-synchronous Twelve-hour Equatorial) orbit. A second viable orbit, also proposed by Ford Aerospace Corporation, is the Apogee at Constant time of day Equatorial (ACE) orbit.[13] It was primarily designed to provide limited coverage at peak traffic times but in constellation form, could also be used to provide more extensive service.

The ACE orbit is highly eccentric, with five revolutions a day. The orbit's passive gravitational perturbations allow a satellite to overfly any given Earth point at the same time each day. ACE has five apogee crossings per day, always above the same point on the equator. These apogee crossings occur every 4.8-hours, are separated 72° of longitude, and remain fixed throughout the year. Other ACE parameters are summarized in Table 4.2. The most important feature of this orbit is that it allows 77-135% more payload to be placed into orbit than does the GSO. Secondary

positive features are an ACE orbit satellite does not approach zenith and its angular separation from the geostationary arc is always greater than 5° for CONUS latitudes. The negative aspects of satellites in ACE

Table 4.2. ACE Orbit Parameters

PARAMETERS	VALUE	UNITS
Period	4.79	h
Semi-major axis	14,445	km
Eccentricity	.49	
Inclination	0.0	°
Perigee radius	7,410	km
Perigee altitude	1,030	km
Apogee radius	21,480	km
Apogee altitude	15,100	km
Nodal regression	-.986	°/day
Apsidal rotation	1.972	°/day

Source: Kent M. Price, Wen Doong, Tuan Q. Nguyen, Andrew E. Turner, and Charles Weyandt, "Communications Satellites in Non-Geostationary Orbits," AIAA Inter-national Communication Satellite Systems Conference, Arlington, Virginia, 13-17 March 1988, (New York: American Institute of Aeronautics and Astronautics, 1988), p. 486.

orbit include their continuous motion with respect to ground terminals and varying slant range and one way signal propagation delay over time.[14]

STET is a circular equatorial orbit with two revolutions per day. Its orbital period delivers it into view over a specified service region at the same time each day, thus it does not rely on perturbations to carry out its mission. Furthermore, tracking STET

satellites is extremely simplified because their path across the sky is constant both in velocity and time. Table 4.3 summarizes the specifics of this orbit. A STET satellite moves from west to east and remains 3.5^{o} away from the geostationary arc as viewed from

Table 4.3. STET Orbit Parameters

PARAMETERS	VALUE	UNITS
Period	12.0	h
Eccentricity	0.0	
Inclination	0.0	o
Radius	26,590	km
Altitude	20,210	km

Source: Kent M. Price, Wen Doong, Tuan Q. Nguyen, Andrew E. Turner, and Charles Weyandt, "Communications Satellites in Non-Geostationary Orbits," AIAA Inter-national Communication Satellite Systems Conference, Arlington, Virginia, 13-17 March 1988, (New York: American Institute of Aeronautics and Astronautics, 1988), p. 487.

Miami. Being lower than the GSO, this orbit allows 23-29% more payload to be placed into space.[15]

Nongeostationary satellite operation requires the use of more costly and complex hardware, both in space and on the ground, than does typical satellite operation. The rising and setting of the spacecraft requires the constant reorientation of the satellite antenna. Since the STET and ACE orbits are closer to the Earth, an earth sensor with a wider field of view is needed. The impact on STET satellites is minimal,

while a satellite in ACE orbit requires the use of a panoramic Earth sensor. Added defensive measures are needed to protect satellites in low Earth orbit from heightened radiation hazards. STET spacecraft using 1990 technology, require 100 mils additional aluminum shielding around sensitive electronic parts plus the use of devices that meet stiffer radiation criteria. The ACE orbit does not require additional shielding, but is heavily bombarded by protons causing damage to solar arrays. To combat this damage, ACE satellites must use arrays with 85% more area plus thicker glass on solar cells. Only 15% more array area is required to offset STET orbit cell damage.[16]

There are many advantages to nongeostationary satellite operation. Satellites which do not require 24-hour coverage can reduce battery reserves by 85%, leaving just enough to perform housekeeping functions during solar eclipses. In addition, the maximum two way transmission delay is .15-seconds for the STET orbit and .12-seconds for the ACE orbit, down from .25-seconds for a geostationary satellite. Finally, lower orbits allow more transponders to be placed on satellites, thus, providing the means to offset the added costs associated with low Earth operation.[17]

Nongeostationary networks can be competitive with geostationary satellite systems. Their cost per transponder can be up to 25% less which is sufficient to offset the costs of system complexities. The main drawback of this analysis is that it only applies to networks which require one satellite to provide part-time service. Systems which need continuous coverage must use constellations of low earth satellites at a considerable cost increase over an equally qualified single satellite. One solution is to use the global coverage capability of the nongeostationary satellite network to provide service to users around the world. Such a multi-satellite non-GSO system would be cost competitive with and have at least the capability of a GSO network. A final caveat on non-GSO equatorial spacecraft is that their potential coverage area is limited. Communications between equatorial regions and low Earth equatorial satellites would interfere with signals to and from the GSO. Fortunately, most of the Earth's population and land mass lies in areas which are serviceable by non-GSO satellites. In any case, considerable coordination effort is needed to ensure that GSO networks do not interfere with low earth networks and vice-versa.

Coordination Techniques

Satellite coordination, as originally coined, is aimed at establishing both frequency and orbital co-existence between planned and existing networks. Coordination in today's progressively deteriorating interference environment, involves the inspection of all technical network characteristics that influence internetwork interference, including orbit location. As a consequence, coordination often requires a new network to make major changes in its design features. In addition, it is sometimes necessary for existing networks to make concessions regarding its technical characteristics (those that do not adversely affect transmission parameters, basic design, interference tolerances, or frequency plans). The increasing GSO population indicates that a certain common discipline must be practiced by all satellite operators, so that new spacecraft can be integrated. One such plan has been implemented in the U.S. It states that,

> "Network users must be prepared to coordinate their networks at a prescribed intersatellite spacing, regardless of the preferred network characteristics. When two networks have the prescribed intersatellite spacing, they are considered coordinatable and are under obligation to coordinate successfully."[18]

This original form of coordination involves only a few spacecraft plus a small part of the orbit.

Such coordination involves not only the determination of orbital positions and operational frequencies but, may also include many of the communication techniques to be discussed in later sections. These techniques and parameters include signal polarization; multiple access; signal power; station keeping; coverage area; signal characteristics; plus antenna main beam size, sidelobe size, and directivity. One recent effort involved INTELSAT and the planned ORIONSAT network. I was informed, by the Orion Satellite Corporation, that the details of this coordination agreement were not releasable, but it is surmisable that it included specifics on many of the above listed parameters and probably more. The success or failure of this effort will probably not be fully known until the ORIONSAT network is fully deployed, around 1993.

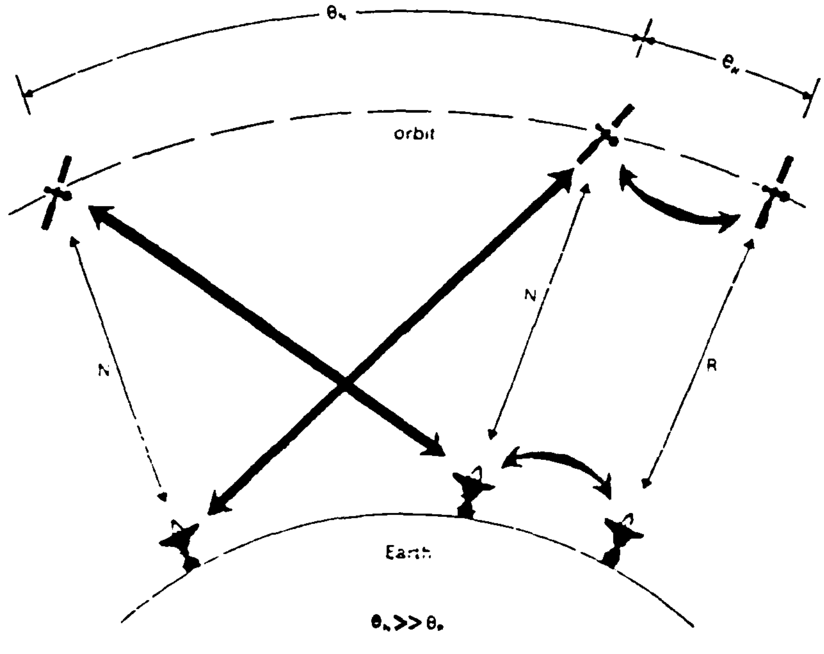
Traditional satellite coordination has very little impact on the whole of the geostationary arc. It does allow a few new satellites to be successfully introduced into the GSO, but in the long run seems to result in the piece-meal coordination of the world's "most important limited natural resources." What is needed are global coordination practices for managing the geostationary orbit. The goal of such techniques is not to add a few more satellites to the GSO but to

collectively increase its overall capacity. To ensue are three methods that promise to fulfill this goal.

Reverse Bandworking

Reverse bandworking is one way to produce a significant increase in GSO capacity. This technique involves using the same frequency band for uplink to one spacecraft as for downlink from another adjacent satellite. In reverse bandworking, the downlink and uplink frequencies are alternated between neighboring satellites. For example, a spacecraft using the 4/6 GHz transmission pattern would be placed between two satellites using the 6/4 GHz pattern. This technique is viable using current technology and fully executed would increase geostationary capacity for portions of the orbit by 70 to 90 percent.[19] Figure 4.2 shows a comparative interference geometry for normal (N) and reverse bandworked (R) communications, with the bold lines indicating interference paths.

Implementation of reverse bandworking does, however, present complex coordination problems with existing satellite systems and terrestrial services sharing the same frequency spectrum. Earth stations, operating with dual direction transmission will cause interference to each other and thus their collocation is prohibited. In addition, when reverse bandworking



Source: Hans J. Weiss, "Maximizing Access to the Geostationary-Satellite Orbit," Telecommunication Journal, Volume 53-VIII, 1986, p. 476.

Figure 4.2. Comparative Interference Geometry for Normal (N) and Reverse Bandworking (R)

is utilized in bands that are shared with terrestrial services, complex interference between these services and both types of networks result. The interference must be controlled by means of additional procedures and interference criteria. This type of band sharing however is, in principle, no different from sharing in regularly operated bands, and its use is merely a matter of adopting acceptable agreements. According to current Radio Regulations, reverse bandworking is allowed only in very limited ways. If it were to be

considered for wider use, amendments to the existing Radio Regulations would be necessary.[20]

Orbit Sectorization

Orbit sectorization involves the placing of systems with similar characteristics (homogeneous systems) in specific sectors of the GSO. Satellites may be grouped for a variety of reasons to include: antenna diameter and receiving sensitivity. Orbit sectorization is based on the assumption that similar systems are less liable to cause interference among each other. This is not to say the conditions which cause interference would be minimized but that the harmful effects of such conditions would be reduced, (e.g. spacecraft are apt to be more tolerant and/or better able to shield against the interfering levels of a homogeneous space system). Thus, similar/more tolerant satellites could be operated at closer GSO spacing intervals.

It is very unlikely that orbit sectorization could be implemented without placing constraints on satellite system characteristics. The most obvious restriction would be limiting the choice of viable orbital satellite positions. This could evolve into an especially difficult problem for high latitude or large countries seeking orbital positions for their

broad-coverage satellite systems, because of their relatively small service arcs. In addition, there may be a need for guard bands to avoid interference at the interface between sectors. In the long run, however, orbit sectorization could optimally provide huge benefits, especially when services to a specific geographic region are harmonious or where there are regional differences in frequency allocations.[21]

<u>Frequency Segregation</u>

Frequency segmentation is another means for increasing GSO utilization efficiency. It is similar to orbit sectorization in that both group satellites by operational distinctions. Spectrum segmentation, though, is based on dissociating satellites by their carrier capacity. The rational is that high spectral density carriers, like television, cause high levels of harmful interference to low capacity ones, such as SCPC carriers (single channel per carrier) used for single telephone channels. To date, the use of the same frequency by carriers of different capacity has necessitated large satellite spacing distances. One method for segmenting frequency bands is by defining the band edges and then placing high density carriers like TV at one edge and SCPC carriers at the other.[22] This graduation of the spectrum band should eliminate

the need for the guard arcs presently used to prevent harmful interference. The end result is an increase in GSO efficiency and capacity.

Communication Techniques

This section on communications techniques and the next section on advanced antenna design will deal with the various methods for efficient utilization of the frequency spectrum. The key to effective orbit-spectrum use is frequency reuse. If each frequency (or band of frequencies) were to be used only once, the capacity of the spectrum-orbit would simply be the total number of transmission channels that can be placed into the available bandwidth. The number of orbiting satellites would be irrelevant as would the distribution of service areas and orbital positions. Frequency reuse is made possible because of advances in antenna discrimination and transmission techniques like signal polarization and multiple access. All of these practices have the potential to either increase the number of satellites which can use the GSO or to expand the transmission capacity of a single orbital position and/or spacecraft or possibly even both. In any case they increase GSO communications capacity.

Signal Polarization

This section will show the beneficial effects that polarization can have on orbit utilization. Two principal situations will be considered. The first, polarization isolation is when alternate satellites use opposite polarizations. The second, often called dual polarization is where all satellites are allowed to use both polarizations. Before going on, a brief review of polarization should be helpful.

Orthagonal polarization is a spectrum reuse technique that allows two signals to be received and transmitted independently at the same frequency. It is a communication technique but also required many advances in antenna design to become reality. The two polarization states place stringent requirements on antennas which must maintain an isolation between states of at least 25-dB throughout the coverage zone of both beams. In the linear mode, the electric and magnetic fields are oriented in fixed planes which facilitate both vertical (north-south) and horizontal (east-west) polarization of electromagnetic signals. In the circular mode, the electromagnetic radiation is sent in opposite directions creating left-hand and right-hand circular polarizations.[23] The result, of polarization, is the amount of information that can be effectively sent in a given bandwidth is doubled.

Usually, two low-noise block-converters (LNB) are required to receive dual polarized signals. They are mounted in series along a circular waveguide. An LNB has its own feed probe and the two are placed at right angles to each other. When this assemblage is rotated to maximize one polarization's signal level, it automatically assures maximum signal at the output of the alternate LNB, with selection of the necessary LNB being achieved by switching DC power supplies. A dielectric depolarizer can be used to modify circular polarized waves so that they can be receive by linear feeds without significant signal loss.[24] Use of more than two polarization levels is theoretically viable, for increasing frequency reuse more than twice. The problem is that discrimination between polarization levels becomes quite difficult when coupled with the accumulated cross-polarized interference components.

When considering polarization isolation, it can easily be deduced that this technique will allow twice as many satellites to be place in the GSO (e.g. satellites can be stationed twice as close together). In reality the actual ratio will depart slightly from this 2:1 because of edge effects. The cause of this effect is a satellites inability to maintain sidelobe polarization purity. For this and other reasons most

satellite users view dual polarization as a superior method of frequency reuse. For co-channel satellite operation, this technique is ineffective at decrease orbital spacing, but it will allow each satellite to transmit twice as much data as a singlely polarized one. Of primary concern when :sing polarization on one spacecraft is maintaining polarization purity in the main lobe of the satellite antenna.[25]

No firm rules can be made with respect to the relative desirability of the two polarization usage methods. Increased orbital efficiency is potentially the same for both methods. Dual frequency use on the same satellite generally requires higher polarization isolation, for a given improvement, than does single polarization per satellite. This, however, does not mean that the former is more difficult than the later because purity of polarization is easier to realize in the main lobe of an antenna than in its sidelobes. The dual-polarization mode will normally be preferred by system operators because twice as much information can be sent from a given satellite. However, close orbital spacing may require the use of polarization isolation for harmonious coexistence. Also, it may be possible to obtain both a spacing reduction and a capacity increase if concurrent carrier interleaving

and polarization used.[26] Carrier interleaving will be discussed in a subsequent section.

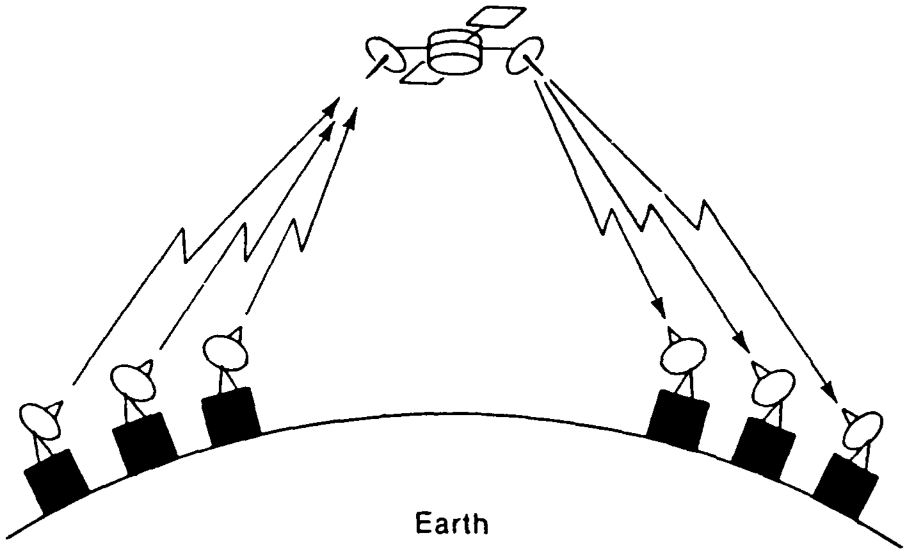
The technical problem related to polarization is depolarization of the signal. The discrimination obtainable between two cross-polarized beams depends on two geographical features: the climate (rain) and the relative locations of the regions to be served by the beams. Depolarization caused by rain will effect both linear and circular polarized signals. Changes in the received polarization angle with latitude and longitude, which may or may not be critical depending on the antenna characteristics, will be present only with linear polarization.[27] Depolarization caused by precipitation is often combatted by simply employing a beam which is readable at alternate earth stations outside of the heavy precipitation area.

Multiple Access Techniques

Multiple access has resulted in a situation whereby a greater number of information channels can be derived from a given amount of power and bandwidth than was possible with previous transmission methods. Its implementation has resulted in the more efficient use of satellite and space segment resources (e.g. power and bandwidth). Multiple access is the method by which numerous users are allowed to share a common

facility. No terrestrial form of communications can come close to the capabilities of spacecraft multiple access communication. This is because satellites can share space segment transmission resources among many small and large users scattered over wide areas up to half the Earth's surface. What this means from a GSO crowding perspective is that instead of launching new satellites, users can share existing space resources. The more efficiently an orbital location is used the less satellites that will be needed to provide this same communications capability. Multiple access is a major contributor to efficient satellite utilization. To follow are the basic access methods used today in satellite communications. Figure 4.3 illustrates the general concept of multiple access.

Time division (domain) multiple access (TDMA) and frequency division multiple access (FDMA) are the two most common multiple access techniques. FDMA is the sharing of a common transponder spectrum band by dividing it into subbands and assigning each of these to requesting users. Each communicating station pair may then subdivide their allocation into individual channels. FDMA features simplicity in Earth station equipment, but it is heavily burdened by multichannel transmission. This results in the need for uplink



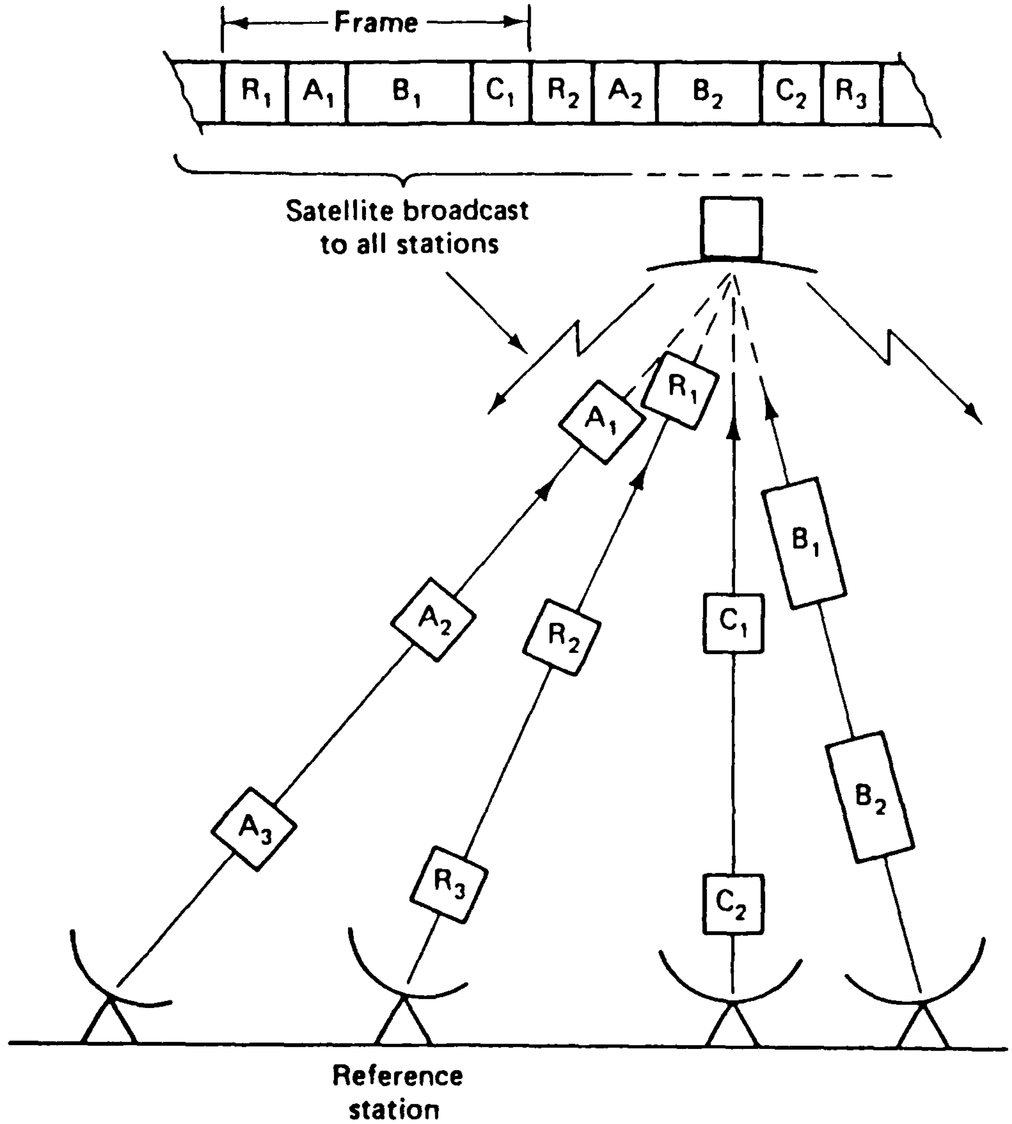
Source: Robert M. Gagliardi, Satellite Communications, (Belmont, CA.: Lifetime Learning Publications, 1984), p. 21.

Figure 4.3. Multiple Access Satellite Links

power control and complex frequency plans with unique assignments, traffic capabilities, and impairments.[28] TDMA provides access to an available transponder on a time-shared basis. One carrier totally occupies the transponder at a time. Each station transmits data in its exclusively assigned time interval, with the duration of the data burst either fixed or varied to fit the station's specific traffic needs. As soon as a station's burst is completed, another station will use its assigned time slot. TDMA attributes include being inherently digital compatible, permitting the

transponder to utilize maximum power capabilities, and being bandwidth efficient. On the down side, it requires more complex and costly earth stations than FDMA because of the need to maintain precise network timing and to operate at burst rates of 60-120 Mbits per second.[29] This often results in the utilization of reference stations to maintain proper operation. The associated extra costs can be especially trying for small traffic stations. Figure 4.4 shows TDMA using a reference station for burst synchronization.

Code division multiple access (CDMA) shares a common transponder by spreading the signal throughout a bandwidth which is much wider than that needed just for information content. This can be done on either an instantaneous or frequency-hopped basis. Transmit stations use a unique pseudorandom code to spread the transmitted signal. A network receiving station must have the same pseudorandom noise (PN) code to recover and despread the information. Other networks operate simultaneously using the same spectrum but different, noninterfering codes for spreading/despreading their data. Interference products will ultimately degrade information bit error rates, but in one actual case this did not occur until six networks were sharing 5 MHz of spectrum. CDMA is interference tolerant and



Source: Dennis Roddy, Satellite Communications, (Englewood Cliffs, N.J.: Prentice Hall, 1989), p. 242.

Figure 4.4. Time Division Multiple Access

privacy oriented but is also a poor spectrum user and needs complex, but often low-cost, earth terminals.[30]

Space division multiple access (SDMA) shares spectrum by making use of geometry orthogonalities in beam pattern or RF signal polarization. Transmitting and receiving stations can use separate polarizations or beams. Filters or switches may be provided on the satellite to allow traffic to flow between uses (e.g. from beam N to beam N+1 or from one polarization to another). SDMA is used in conjunction any previously mentioned multiple access technique.[31] Contention by operators for the use of a facility is called random multiple access (RMA). It is attractive to small and low-duty-cycle users because of the limited amount of control equipment that is required. The facility may be available on either a random basis (uncontrolled, unorganized, unscheduled) or with levels of control. In the former, performance is varied (it is sensitive to traffic amounts), thus as traffic builds, controls are often needed to keep retransmission to find clear channels, at a moderate level. Sophisticated systems have multiple control levels which may be switched to under various traffic conditions.[32]

In demand assignment multiple access (DAMA), transmission resources are assigned to customers only when needed and after use, returned so that they may be used by other customers. Demand assignment can be

on either a frequency or timed basis, with operation the same as FDMA and TDMA respectively. However, in actual practice, timed DAMA is usually a combination of time and frequency division since it uses several high-bit-rate carriers of different frequencies. The assignment to the space segment channels is typically performed on a regulated basis by network controllers that specifically assign space segment channels to a user upon demand. Assignment may also be achieved by RMA in a manner similar to that previously listed for this technique. The random access mode is typically performed by time division of a carrier shared among a group of small earth terminals and is used for the popular and rapidly growing VSAT node/hub satellite data communication system.[33]

The various multiple access techniques have their strengths and weaknesses. The smart satellite operator will mix and match the various methods to achieve optimal results. In any case, what is best for one system and/or user may be totally wrong for another. Efficient satellite use is ultimately the goal. Operators may only be increasing efficiency for strictly monetary reasons, but regardless of the motivation the result is a more efficient use of the geostationary satellite orbit. With that being the

name of the game, multiple access has been and will continue to be a valued element in meeting our goals.

Other Techniques

Additional methods for increasing satellite efficiency and/or reducing orbital spacing (guard arc can be reduced when systems are less sensitive to the effects of interference), are modulation schemes that are tolerant to interference, improved filtering to reduce interference on adjacent channels, and methods for interference cancellation (much R&D is needed in this area). Two techniques to be discussed here are frequency interleaving and spread spectrum.

When frequency channels are interleaved in a way such that the coincidence of carrier frequencies is avoided, mutual interference can in many cases be greatly reduced. The frequency differences between mutually interfering carriers is one of the very few conditions, contributing to interference, that can be easily changed. It can be established more or less arbitrarily, within limits, without affecting major design parameters and at virtually no inconvenience or cost, except for, coordination before the fact.[34]

Spread spectr[illegible], originally used for military and covert communications, is now available for other users who desire security and interference immunity.

Thus, with the need for greater interference tolerant space systems, spread spectrum could receive a great deal more attention. It requires the use of a wide spectrum, usually on a shared basis, in addition to coding, decoding, and synchronization equipment. At one time this equipment was extremely expensive but with advances in large-scale integrated circuits, the size and cost of such equipment has been drastically reduced. Spread spectrum has two primary operational modes, spread spectrum and frequency hopping. Some detail on the specifics of these two techniques was presented in the previous section on CDMA. However, for the purposes of this paper, it is only important to recognize spread spectrum's value in relation to the GSO crowding problem. That being its ability to minimize the impact of interference, thus permitting reduced intersatellite spacing.

Advanced Antenna Designs

Advances in antenna design have resulted in the largest increases in satellite and geostationary efficiency and should continue to do so into the next century. Spot beams and specially shaped beams allow considerable reuse of available spectrum. Antennas are being designed to minimize the amount of sidelobe

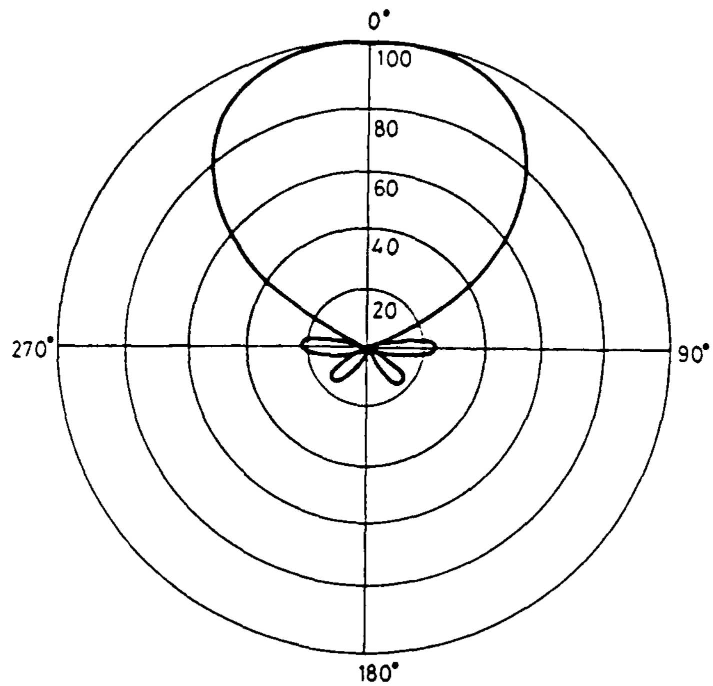
radiation, thus reducing interference between systems and allowing closer satellite spacing. In addition, computers are being used to shape antenna patterns. The closer an antenna beam matches its coverage area, the more efficiently orbital positions can be used.

One of the driving factors in recent antenna advancements was the FCC's order to reduce satellite spacing in the U.S. to 2^{o} by 1 January 1987. To meet this challenge, the satellite communications industry was forced to implement many changes in order to gain interference-free communication. This conversion was especially difficult for earth stations using 5 meter and smaller antennas (in 1986, this was one-third of all transmit stations and nine out of ten licensed receive-only stations).[35] Industry reacted to this situation and will continue to react into the future. There is every reason to believe that if satellite spacing were reduced tomorrow, industry would again respond successfully. Some antenna basics are needed prior to starting on antenna efficiency enhancements.

Antennas convert electronic carrier signals into polarized electromagnetic fields and vice-versa. A transmit antenna consists of a feed assembly which illuminates an aperture or reflecting surface. From there the electromagnetic field radiates. Receiving

antennas use the aperture to focus a radiation field to a collecting feed. Thus, an electronic signal is produced which is proportional to the received field. For most communication purposes, antenna beams should be highly directional, with maximum gain concentrated over a narrow beamwidth and small sidelobes.[36] Beamwidth and sidelobes are the two characteristics which contribute most to interference and, thus most limits satellite orbital spacing. A typical antenna pattern is shown in Figure 4.5. Since an antenna's structure and size are perhaps the easiest to modify, hardware wise, this is often the starting point for improving antenna efficiency and performance.

Antennas, unfortunately do not radiate all of their energy into the transmission beam, but emit a significant amount in other directions, particularly into the sidelobes adjacent to the main beam. This radiation can interfere with communication. Orbital spacing is determined in part by the power levels in the sidelobes and the sensitivity of adjacent systems to interference. Advances in antenna design should reduce sidelobe radiation and allow closer satellite spacing. In addition, the communications techniques listed in the previous section should reduce system sensitivity to sidelobe interference, and thus would

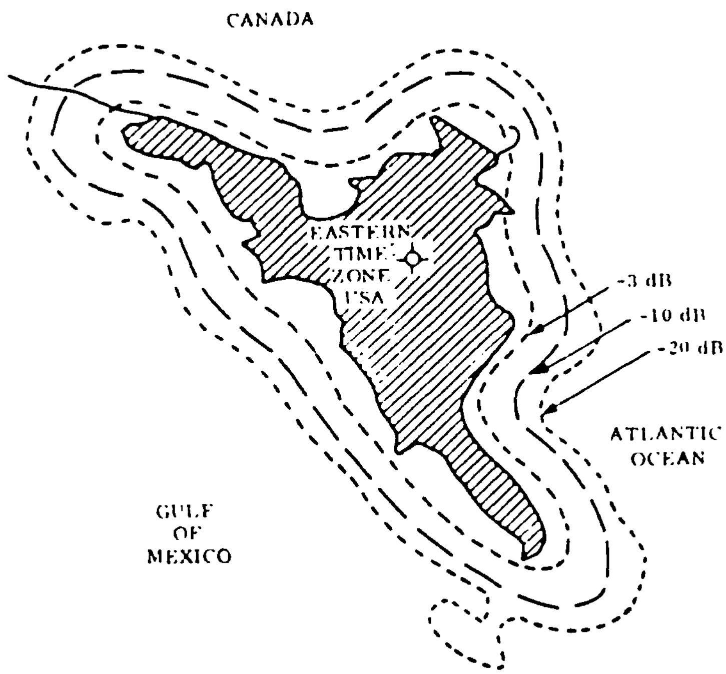


Source: B. Claydon, "Introduction to Antennas," In Satellite Communication Systems, Ed. B.G. Evans, (London: Peter Peregrinus Ltd., 1987), p. 75.

Figure 4.5. Antenna Radiation Pattern Representation

also permit closer satellite spacing.

Large service areas tend to be irregular in shape. Being large, they also tend to require high satellite transmitter power. Today's antennas can minimize this power by generating satellite antenna main beams which approximately reproduce the shape of the service area. Figure 4.6 illustrates how such a shaped beam pattern would look and also its estimated gain roll-off. This type of beam shaping results in



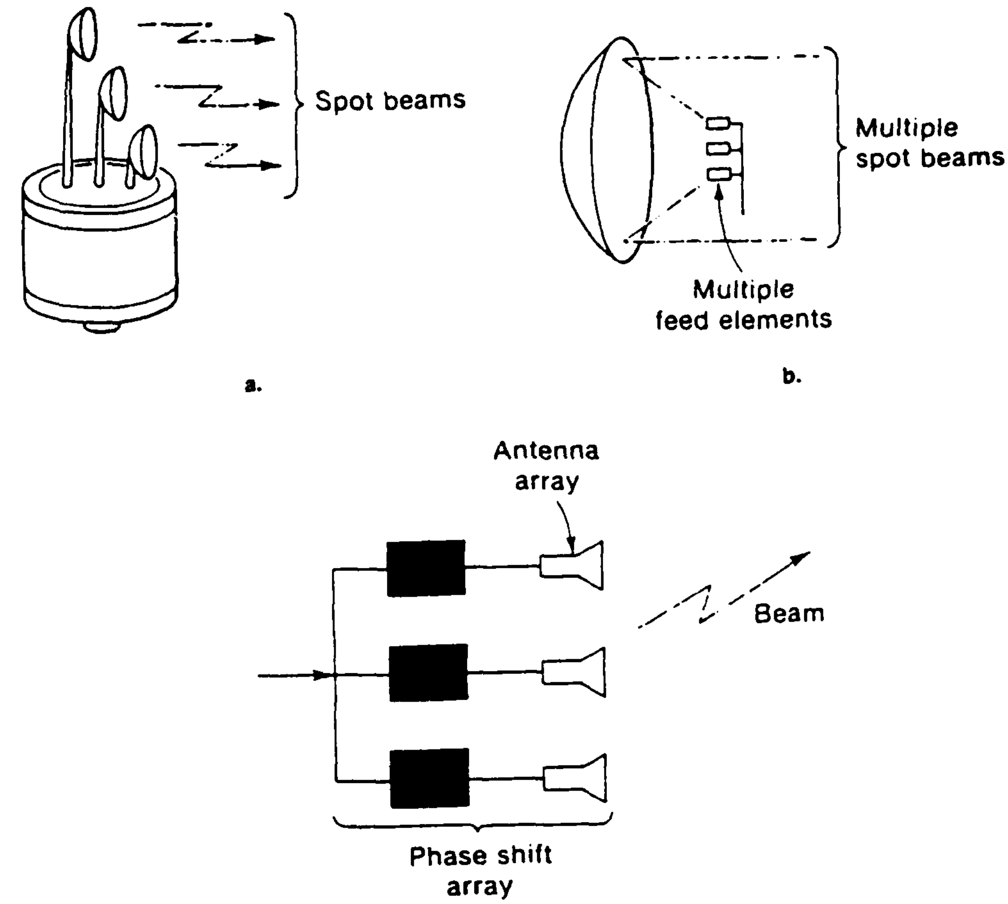
Source: Donald M. Jansky and Michel C. Jeruchim, Communication Satellites in the Geostationary Orbit, (Norwood, MA.: Artech House, Inc., 1987), p. 235.

Figure 4.6. Shaped Satellite Antenna Beam Pattern

an advantage to the satellite operator, in the form of reduced power, viability of smaller earth station antennas, and increased network capacity. These same effects also tend to increase the efficiency of orbit utilization. Specifically, beam coverage is reduced which allows greater separation between service areas and a faster gain roll-off in the satellite antennas' out-of-coverage radiation characteristics.[37]

Spot beams have proved to be very beneficial when used to service large coverage areas which have widely separated geographic communities, particularly when they form distinct and separate traffic models. Benefits result from reduced power requirements due to the fact that those parts of the Earth's surface which neither originate nor receive traffic are not illuminated. The final result is improved orbital efficiency since, as with shaped beams, separation between coverages is increased and orbit spacing is decreased. In addition, the narrower the spot beams can be made, the greater the potential for frequency reuse from the same orbit location (this is of more interest at higher frequencies).[38]

Frequency reuse can be obtained through the use of multiple spot beams from the same satellite. Multiple beams can be produced in one of three basic ways, see Figure 4.7. The simplest involves the use of separate antennas for each beam, with each pointed to a given service area. This configuration, though bulky, results in maximum isolation between feeds and little beam interference at the satellite. Multiple beams can also be produced from a single reflector by using multiple feeds. The feeds illuminate a common dish, which focuses the individual radiation fields



Source: Robert M. Gagliardi, Satellite Communications, (Belmont, CA.: Lifetime Learning Publications, 1984), p. 129.

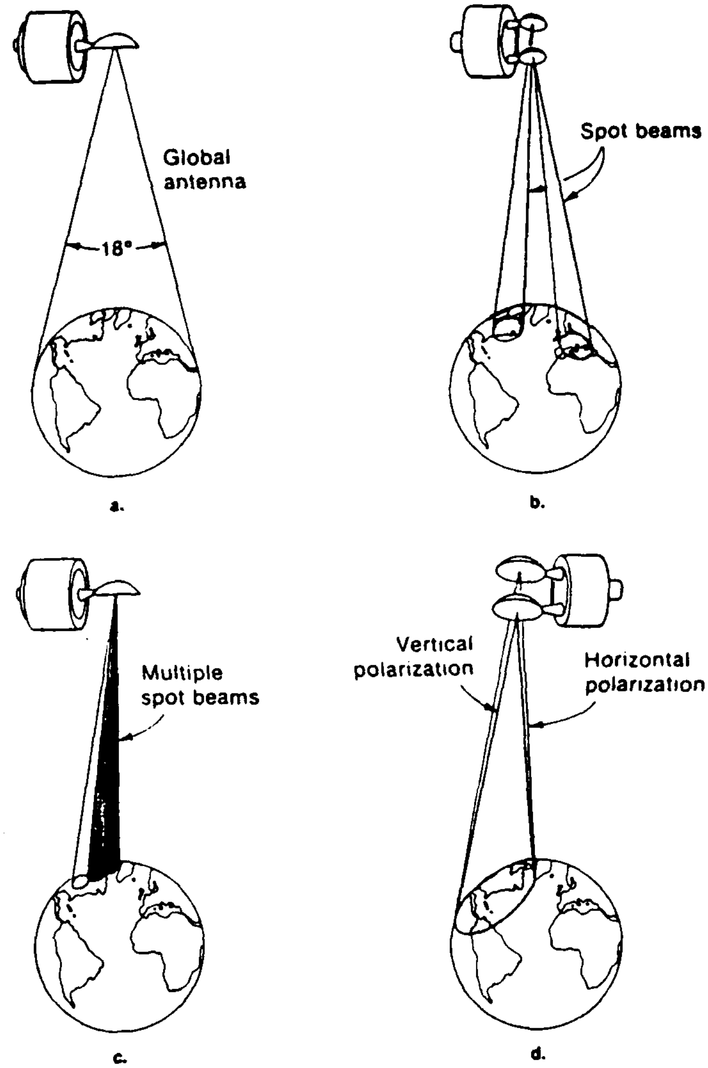
Figure 4.7. Multiple Beam Antennas
(a) Separate antennas (b) Multiple
feed, single reflector antenna
(c) Phased array antenna

in specified directions. Direction, of the desired spatially separated spot beams, is specified by off-setting the feeds and positioning each to point to a different section of the dish. Frequency reuse can

be obtained by directing each beam to distinct areas or through the use of polarization (each beam has the polarization of its feed). By properly positioning a group of feeds so as to slightly overlap their spots, they produce the formerly discussed shaped beams. A third method for producing multiple beams is by using phased antenna arrays. It was originally devised for use on the TDRS system.[39] Other operational details of this method are unnecessary for further dialogue.

The main problem with multiple beam frequency reuse is avoiding interference among adjacent beams. Preventing this requires careful spot beam separation and shaping, to reduce beam spill-over. One way to reduce this interference is for adjacent beams to use separate frequencies. Receiver filtering also helps to reduce adjacent beam spill-over, but the required total filtering range also increases. Some degree of frequency reuse is still possible since only adjacent beams need have band separation. Last, by increasing the number of usable bands for a given number of spot beams, better isolation is available but the data per total bandwidth decreases.[40] Figure 4.8 depicts four of the various methods for using spacecraft antennas.

Until recently, it was assumed that all spot beams were to be pointed permanently in a specified



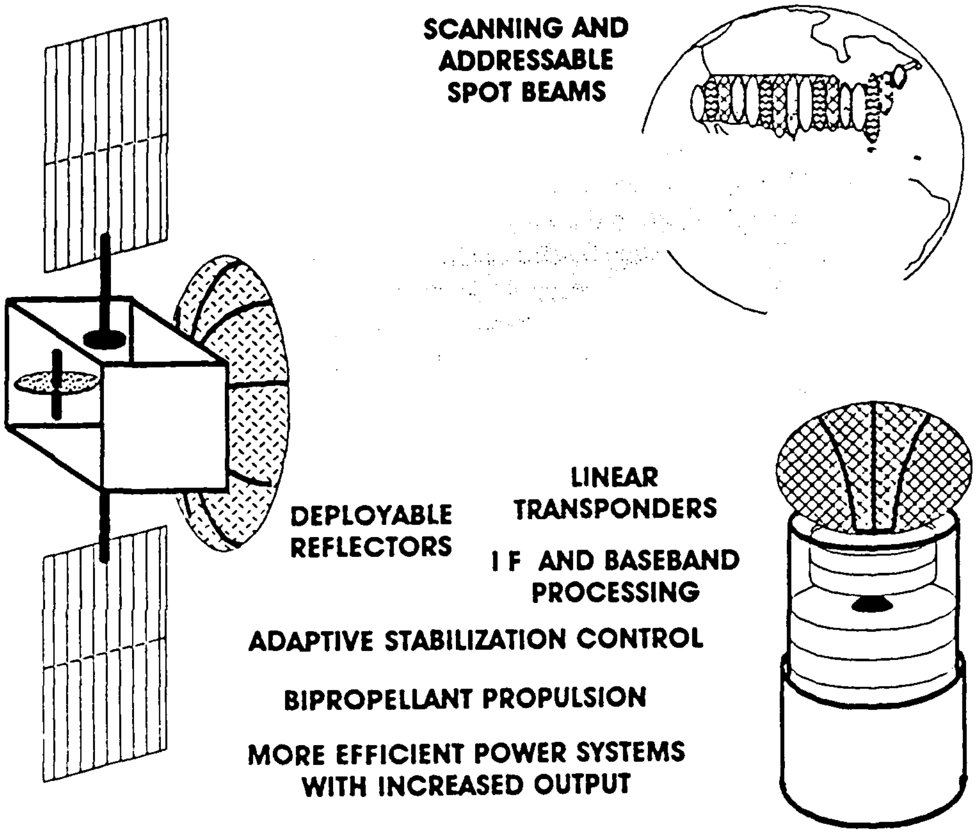
Beamwidth	Earth coverage diameter
10°	3921 miles
5.7°	2235
2.8°	1117
1.0°	392
57°	223

Source: Robert M. Gagliardi, Satellite Communications, (Belmont, CA.: Lifetime Learning Publications, 1984), p. 127.

Figure 4.8. Antenna Beams
(a) Global (b) Dual spot (c) Multiple spots (d) Dual polarized spot beams

direction. It has been shown though, that in certain situations, scanning spot beams can make optimal use of a satellite's resources. They have been shown to be particularly effective in areas where there is low traffic density. Spot beams, in additional to being more economical, also reduce interference because at any one time there are less beams than service areas. This is but one more way that satellite effectiveness and GSO capacity can be increased.

Because of their many advantages, multibeam antennas have come into considerable use in the last decade. Their versatility allows them to produce not only fixed and scanning spot beams but also contoured beams. Adding polarization to these practices allows interference free spot beams to be even more closely spaced resulting in frequency reuse over CONUS up to 12-times.[41] Figure 4.9 illustrates frequency reuse from scanning and addressable spot beams plus some of the other developing technologies for communications satellites. This technology is best applied in "Ku" and "Ka" bands, because these higher frequencies make smaller spots for the same size of satellite antenna. In the figure, each slice of the service area is tied to a selected portion of the frequency band, with the assignment of each portion repeating according to the



Source: Bruce R. Elbert, Introduction To Satellite Communication, (Norwood, MA.: Artech House, Inc., 1987), p. 331.

Figure 4.9. Frequency Reuse Using Spot Beams

sequence of shading. In this example, the allocation of 500 MHz would be used four times, resulting in an effective bandwidth of 2000 MHz. Because these spot beams are narrow, cross polarization is not needed to isolate the beams. Thus, a second polarization could be reserved for another service or to allow placement of another satellite at the same orbital position.[42]

Reconfigurable satellite antennas, like those to be launched on EUTELSAT II in early 1990, will be capable of reconfiguration between low and high EIRP channels. This will be accomplished by switching off some antenna feeds and concentrating energy to just a few feeds. This capability should become especially important in the future when satellites have extended life-spans. Satellite efficiency over time will thus increase due to the ability to change coverage areas to meet changing traffic demands, to modify coverage areas upon satellite relocation to a different orbit location, to provide interference discrimination, and to increase system tolerance.[43]

The last antenna area to be covered will be the methods by which increasingly more stringent beam pointing accuracy can be obtained by on-board antenna subsystems for future satellite missions. For some missions, the spacecraft AOCS (attitude orbit control system) may not be able to performing this task. In these cases it may be necessary for the control loop to include an RF sensor, integrated into the antenna, which needs precision pointing. It would be used to lock the beam on to a ground beacon positioned within the required coverage zone.[44] As the requirement for smaller spot beams is imposed (to meet requirements

for more efficient satellite utilization), there will be a growing demand for more sophisticated RF sensing techniques. Ultimately resulting in them becoming an integral part of most satellite antenna designs.

Use of Higher/More Frequencies

The most obvious answer to the geostationary orbital crowding problem is to use more transmission frequencies. From a technical stand point, the most logical place to add frequencies is in the already existing transmission bands (e.g. the extension bands authorized by the 1979 Space WARC). Unfortunately, most transmission bands are presently saturated by current terrestrial and space services. With current services already crying for additional spectrum, it is unlikely that anyone could persuade them to give up their valuable resources to accommodate additional space services. Also since satellite communications is better suited to operation at higher frequencies it only makes sense that this is where the expansion should occur.

A great deal of radio spectrum is available for use above 10 GHz. This spectrum can be used to satisfy the demand for added communication satellite frequencies. The use of these higher frequency bands

will permit greater antenna directivity, specificity, and discrimination. In addition, interference with terrestrial services will be low because very few use these bands. The higher frequency bands also tend to have wider bandwidths available. For instance, 3,500 MHz of bandwidth is available between 17 and 31 GHz. Unfortunately, there are also disadvantages to using these higher frequencies. A major one being the cost to implement a high frequency system versus one at an established lower frequency.[45] Another fundamental limitation associated with satellite communications above 10 GHz is the strong interaction of radio waves with rain and ice in the lower atmosphere. Design of an economical and reliable spacecraft communications system for use in upper radio frequency bands depends on a detailed knowledge of these propagation effects.

The next frequency band to be used widely for satellite communications is the 30/20 GHz band where 3-5 GHz is available in each direction. Once again, systems which operate at these frequencies must cope with disturbances caused by the atmosphere, rain in particular. Designing systems capable of effective operation under these conditions, is a new challenge for today's communications engineers. The end result will be increasingly more complex and costly systems.

One area where the effects of atmospheric propagation can be minimized is to use the part of the "Ka" band assigned to mobile service to communicate with planes in flight.[46] Japan's fixed communications satellite system was the first to use frequencies in the 30/20 GHz band.[47] However, because of the ability to use smaller antennas and the wide bandwidth allocated to fixed-satellite service, it is anticipated that this band will receive wider use in the future, leading to a more efficient use of the GSO and frequencies.

The use of even higher frequencies may become possible in the coming years. The U.S. Department of Defense's MILSTAR program for example, is expected to become operational in the early 1990's. It should be the first space communication system to operate at an extremely high frequency (EHF), approximately 45 GHz for the uplink. Its downlink, approximately 21 GHz, is in the super high frequency (SHF) "Ka" band. The use of these high frequency radio signals is driven by their resistance to the effects of nuclear weapons and their ability to provide privacy through the use of small spot beams. They also allow use of smaller ground terminal antennas, an important consideration for aircraft and other mobile users.[48] Even though

this system was designed for military use, many of its attributes can be used for commercial advantage.

Future Alternatives

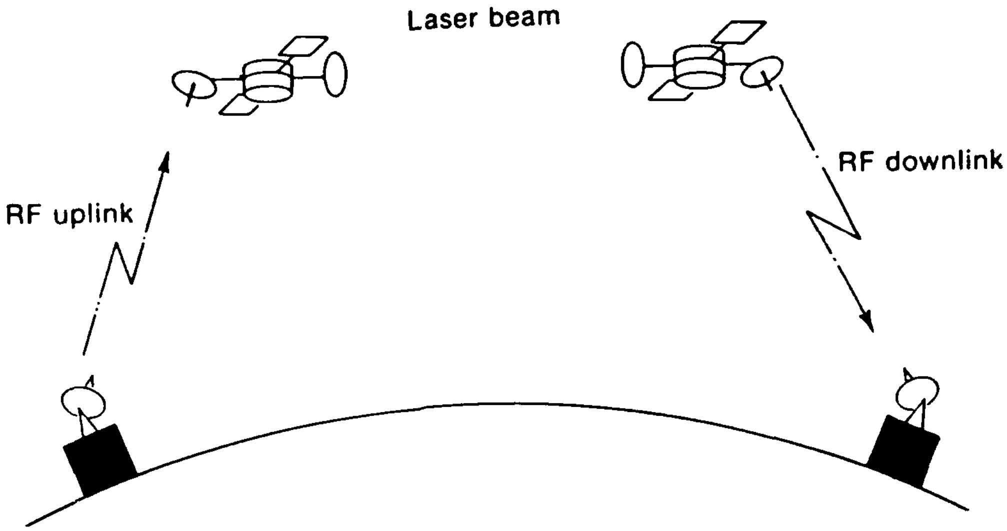
The future of satellite communications looks to be very promising. On the horizon are advances in many areas such as nickle hydrogen batteries, gallium arsenide solar cells, ion engines, laser technology, and smaller and smaller microcircuits. These are the advances that will blaze the way toward new horizons in power generation, station keeping, communications technology, and on-board command and control systems. Many of these advances were only seen in the visions of science fiction writes fifty years ago, but like the Clarke orbit they are becoming reality today. To follow are four examples of how advancing technology is used now and will continue to be utilized in the future to advance the state-of-the-art in GSO use, efficiency, and performance.

Intersatellite Links

The idea of intersatellite links (ISLs) is not new or futuristic but its implementation is in the infancy stage, with many new methods and uses in the planning. ISLs were first planned for and placed into use on military satellite networks. A few such

systems are in use today. The basic function of an ISL is to provide a connection between geostationary satellites (the Strategic Defense Initiative System, (SDI/SDS) proposed links between satellites in other than geostationary orbits), and from this simple fact emerges their beneficial properties. They prove most beneficial when the connection they are augmenting is between two earth points that are impossible to join via a two-hop network, or to do so would result in an undesirably low elevation angle. ISLs are also used to provide satellite position flexibility when normal operational conditions exist. This can be especially useful when a satellite employs spot beams. A basic satellite crosslink model is depicted in Figure 4.10. The shown laser beam link could easily be replaced by an RF transmission link.

The following are the major benefits of using intersatellite links: 1. They allow networks to meet increasing connectivity requirements without adding additional ground terminal antennas. 2. They permit interconnection of widely separated ground terminals that otherwise could only be served by double-hopped transmissions. 3. They ease satellite orbit position constraints that relate to improving the operational performance of multinetworks. As an extension, orbit



Source: Robert M. Gagliardi, Satellite Communications, (Belmont, CA.: Lifetime Learning Publications, 1984), p. 382.

Figure 4.10. Satellite Crosslink Model

crowding is eased when positioning flexibility allows satellites to be placed in orbital locations that are less congested than might otherwise be needed without an ISL. 4. They permit separate-coverage networks to consolidate coverage areas. 5. They permit broadcast satellite networks to share programs internationally. 6. They allow the resources of individual satellites to be shared, resulting in more efficient use of the communications capacity of the total space network.[49]

Now for some more detail on how ISLs can be used to increase GSO efficiency and use. First, they have been cited as a way to increase the homogeneity among satellites. Like spacecraft can typically be

placed closer together without causing harm. This leads to closer satellite spacing and more orbital slots. Next, direct satellite-to-satellite relays, like those used on the TDRS system, could be used by satellites serving global or very large service areas when optimal GSO slots are unavailable. Thus, a more adequate use of the Clarke orbit. Third, earth sites more than about 8,000 kilometers apart usually need an intermediate ground station and a second satellite to facilitate communication. This uses twice as much of the GSO and radio spectrum as communications using a single satellite. Such networks should be replaced by satellites with direct interconnectivity, avoiding "double hops." This replacement system would consist of satellites with long service arc, allowing greater flexibility in the choice of orbit positions. Last, ISLs would aid coordination between global and large coverage area systems and domestic or small coverage area systems by permitting reduced coverages.[50] Once again increasing satellite efficiency.

ISLs in themselves are resource efficient in that they can use spectrum currently unused by other satellite systems. They use the frequencies that are subject to high atmospheric attenuation, and thus are not suitable for satellite to ground communications.

The most common spectrum listed for this purpose are 60 GHz and optical bands. As a final note, ISLs are not currently seen as a viable near future substitute for global beams. The reason being that they carry a large implementation and economic penalty due to the number of additional satellites and the technological sophistication required. However, for the purposes listed above they represent a valuable addition to the communications satellite arsenal, for use in the fight to win the GSO crowding battle.

Satellite Clusters

A satellite cluster is one proposed method to increase the communications capability of an orbital position. It becomes an even more desirable prospect with the telecommunications growth trend such that it will eventually exceed the capability of present and planned launch vehicles, to satisfy satellite payload requirements. What this means is, soon there will be the need to launch larger communications satellites than proposed technology allows. One solution is to divide the payload into several segments, mount each on a separate spacecraft, and operate the collection of spacecraft in such a way that they appear as one to the earth-based user. This is the concept of the satellite cluster (e.g. several separate and distinct

satellites co-operate to provide service greater than each could provide on its own). The characteristics and size of the cluster would depend on the specific needs of the users. Several variations are possible, ranging from master/slave to co-equal configurations, structures with full communication interconnectivity to those with no interconnectivity. In addition to not being limited by launch vehicles, clusters also can be implemented in stages to match demand.[51]

Regardless of specifics, the cluster is only attractive if satellite payload divisions are lucid to the user. For different users this could imply a host of different things. One thing for sure is that a cluster must follow the same station keeping rules currently imposed on single satellites. This implies tighter control on spacecraft position and velocity (both in absolute and relative terms) than has been necessary in the past. Such accuracies are already available with current technologies. There are many possible geometries available for satellite clusters, with each having their strengths and weaknesses. For example the simplest is when satellites are stationed side by side along the geostationary arc. The draw-back to such a structure is that intersatellite lines

of sight are coincident, thus only near neighbors can communicate directly.[52]

An important observance, when evaluating the satellite cluster, is to realize that it may or may not, in itself, be a final product but may be merely a useful transitional step toward the space platform. To follow is some information which may be helpful in evaluating the long term usefulness of the satellite cluster. It is based on a comparative study of up to ten satellites spaced 10 km apart: 1. Cluster design is a "Catch 22" problem. If you specialize satellite design to achieve cost efficiency by putting certain functions on certain cluster members, you have the offsetting disadvantage of needing multiple spares. A cluster with identical satellites requires a single in-orbit spare and thus is more cost effective than a conventional satellite and can also derive much more usable capacity from a single orbit location. 2. An ESA design envisions 100 different beams allowing 200 fold frequency reuse from a single location when dual polarization is used. 3. Effective cluster operation needs both local and regional intersatellite links.[53] One thing for sure the current GSO crowding situation demands that satellite clusters be an integral part of future space communications plans.

Space Platforms and Multipurpose Satellites

Multipurpose satellites which combine two or more missions into a single satellite is one means of reducing the risk of GSO overcrowding by reducing the total number of satellites. The proposal is to use a single satellite to either serve the needs of several countries or the various demands of a single country. Such systems cost each country or user less and will contribute less to geostationary orbital congestion than establishing satellites for each nation or user, particularly when their demand is low. INSAT-1A, the Indian National Satellite, could be labeled the first true multipurpose satellites. It was a three in one spacecraft with these major objectives, 1. voice and data communications between major areas within India (telecommunications) 2. audio and video transmission for direct broadcasts to low-cost radio, television, and disaster warning receivers throughout the country (broadcasting) 3. VHRR observation and transmission of data to meteorological centers and real time relay of data from remote data collection platforms to the meteorological centers (meteorological services).[54]

Multimission space platforms or antenna farms have also been suggested as a way to more effectively use the radio spectrum. They would accomplish this by permitting more flexible switching between ground

networks, geographic regions, and potentially between intersatellite or interplatform links. The satellite platform is a space structure which will most likely be assembled in a low Earth orbit (a space station), and then carried to the GSO, by an orbital transport vehicle (OTV), where it would be placed into service. Such a platform would have the following attributes: 1. There would be no limit on its size and weight or that of its components. There could be infinite power generation. Complex and large antennas of all kinds could be implemented. Almost every mission could be realized. 2. The number of satellites, and thus the burden on telemetry, tracking, and control centers would be lessened. Service life could be extended by repairing equipment and adding fuel and demand could be met by adding new equipment and services. The end result would be a drop in service costs. 3. It would have improved reliability because space verification could be performed in low earth orbit. For these and other reasons, it is believed that multipurpose space communications platforms and space stations will make up the space infrastructure of the future.[55]

Space platform implementation would require advanced technological development in the following areas: satellite switching, deployable antennas, low

noise receivers, high output transmitters, multibeam satellite antennas and transponders, as well as Earth station technology relevant to the above items. The development of high-efficiency, high production power systems and easy to assemble, connect and disconnect structural modules is also necessary. Technology for OTVs, rendezvous-docking, and assembling structures in outer space must additionally be advanced. As is evident here, this is no small challenge, but based on this technology, an experimental platform could be built by the year 2000, with operational platforms to follow soon after.[56]

The disadvantage of large multimission space platforms is that in addition to relying on the above technological advances, they also present substantial coordination and technical design problems. Another drawback is that, until space repair and maintenance becomes routine, they may be reliability liabilities. Since, current and foreseeable transportation systems may be unable to launch large preassembled platforms, their construction appears to require the support of inhabited space stations.[57] It is obvious that the advantages of such systems are at least 10-15 years away. In the near term, it is important that we not abandon the use of multipurpose satellites. As they

grow too large to launch, the next logical step is the satellite clusters, and finally the multipurpose space platform. Using this progression will assure that space communications resources are available for many years to come.

Low Earth Geostationary Satellites

Low earth geostationary satellites would help to solve many problems associated with communications to the traditional geostationary orbit. The first of those is that, it would help to alleviate the current congestion problems (orbit and frequency assignments) that exist their. As a bonus, such satellites would also lessen the problems associated with transmission delay and signal power levels. Nothing however, ever comes for free and low earth geostationary satellites are no exception. The price here is the research and development time and money needed to solve problems such as station keeping in the upper atmosphere and the power supply needed for this type of endeavor. But, where there's a will there's a way and what you are about to hear may sound like science fiction but then again aren't most good long range technological proposals, like landing on the moon, "Star Wars," and the Space Station.

The geostationary satellite orbit is nearly one-tenth of the way to the Moon. This equates to a 250-millisecond delay for signals sent from Earth to a spacecraft in GSO and then back again to Earth. In addition, compensation is required for the dispersal of energy as the signal travels along this path. How should this problem be handled? Should it be offset with built-in transmission delays and high intensity transponders or with alternative solution? Currently the choice is compensation but at the same time long-term studies are being pursued to explore the option of maintaining satellites in geostationary positions at altitudes under 1000 miles.

One concept under study is called Spidersat. The proposal is to use ground based microwave power sources, perhaps four of them, to beam-up the power necessary to stabilize a very light weight gossamer antenna and its supporting solid state electronics. With all on-board satellite power supplied from the Earth, there would be no need for batteries or solar arrays. It would be possible to augment the ground supplied power by the use of ion engines. Thus, the enormous amount of power is available to permanently stabilize the Spidersat craft over a location several hundred miles above the surface of the Earth. There

it could be used to provide domestic communication or to relay signals around the world. The mass of such a satellite would probably be less than 100 kilograms and it would benefit from nearly a zero second signal propagation time delay and extremely low transmission path losses when compared to GSO satellites.[58]

NOTES-CHAPTER IV

[1] Joseph N. Pelton, "21st Century Satellite Communications," Via Satellite, December 1988, p. 28.

[2] Pelton, p. 28.

[3] "FCC Survey Finds 39 Percent of U.S. Satellite Transponders Idle," Data Communications, February 1987, p. 58.

[4] Tom Ivall, "Molniya Orbits for Car and Mobile Radios?" Electronics & Wireless World, November 1987. p. 1158.

[5] Ivall, p. 1158.

[6] Donald M. Jansky and Michel C. Jeruchim, Communication Satellites in the Geostationary Orbit, (Norwood, MA.: Artech House, Inc., 198[illegible]), p. 273.

[7] There are various techniques used to track satellites. Radio and radar trackers can work in any weather condition. Radio tracking uses the signals radiated by the tracked object to monitor its course. In radar tracking, a signal is transmitted, when this signal is received by the tracked object, it reflects or is retransmitted back so that its progress can be followed. Optical tracking can be employed only if visibility is good. Even cheap optical trackers can give accurate results comparable to that obtained by radio tracking systems. Advanced optical techniques can yield accuracies as good as those obtained by the best alternative trackers. Infrared tracking depends upon the heat energy radiated by the tracked object. Infrared trackers unlike optical trackers, are not dependent on the observed surface being sunlit.

[8] Tom Ivall, "Geostationary Loops?" Electronics & Wireless World, September 1988, p. 903.

[9] Ivall, "Geostationary Loops?", p. 903.

[10] Ivall, "Geostationary Loops?", p. 903.

[11] Coverage areas are areas in which the PFD (power flux density) on Earth, during the passage of the spacecraft from the intersection of the loop top and back again, corresponds to at least that which is generated at the top of the loop, at the 3dB contour.

[12] Ivall, "Geostationary Loops?", p. 903.

[13] Kent M. Price, Wen Doong, Tuan Q. Nguyen, Andrew E. Turner, and Charles Weyandt,"Communications Satellites in Non-Geostationary Orbits," AIAA International Communication Satellite Systems Conference, Arlington, Virginia, 13-17 March 1988, (New York: American Institute of Aeronautics and Astronautics, 1988), p. 485.

[14] Price, pp. 486-487.

[15] Price, p. 487.

[16] Price, p. 488.

[17] Price, pp. 488 and 491.

[18] Hans J. Weiss, "Maximizing Access to the Geostationary-Satellite Orbit," Telecommunication Journal, Volume 53-VIII, 1986, p. 476.

[19] Rita Lauria White, and Harold M. White Jr. The Law and Regulation of International Space Communications, (Boston: Artech House, Inc., 1988), pp. 16-17.

[20] Weiss, p. 477.

[21] White, pp. 18-19.

[22] White, p. 19.

[23] Timothy Pratt and Charles W. Bostian, Satellite Communications, (New York: John Wiley & Sons, Inc., 1986), pp. 86-87.

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[26] Jansky, pp. 146-150.

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[29] Morgan, p. 403.

[30] Morgan, p. 402.

[31] Morgan, p. 403.

[32] Morgan, p. 402-403.

[33] Joseph S. Campanella, "Communication Satellites of the Future," Telecommunication Journal, Volume 55-III, 1988, p. 192.

[34] Robert M. Gagliardi, Satellite Communications, (Belmont, CA.: Lifetime Learning Publications, 1984), p. 155.

[35] John Airgood, Kurt Oliver, and Kenneth Ryan, "This Is the Year for the Operators of Earth Stations to Upgrade for the Two-Degree Spacing of Satellites," Communications News, March 1986, p. 48.

[36] Gagliardi, pp. 87-88.

[37] Weiss, p. 474.

[38] Weiss, p. 474.

[39] Gagliardi, pp. 128-130.

[40] Gagliardi, p. 128.

[41] James W. Bagwell, Technology Achievements and Projections for Satellites of the Future, (Cleveland: National Aeronautics and Space Administration, Lewis Research Center, 1986), p. 3.

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[43] Francesco Rispoli, "Reconfigurable Satellite Antennas: A Review," Microwave and RF Engineering, April 1989, p. S22.

[44] B. Claydon, "Earth Station and Satellite Antennas," In Satellite Communication Systems, Ed. B.G. Evans, (London: Peter Peregrinus Ltd., 1987), p. 212.

[45] White, p. 21.

[46] Pierre Bartholome, "Future Trends in Satellite Communications," In Satellite Communication Systems, Ed. B.G. Evans, (London: Peter Peregrinus Ltd., 1987), pp. 398-399.

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[50] White, pp. 19-20.

[51] J.J. Pocha, An Introduction to Mission Design for Geostationary Satellites. (Dordrecht, Holland: D. Reidel Publishing Company, 1987), p. 118.

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[53] Joseph N. Pelton, "Satellite Telenets: A Techno-Echonomic Assessment of Major Trends for the Future," Proceedings of the IEEE, November 1984, p. 1453.

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[56] Miura, pp. 522-530

[57] White, p. 22.

[58] Pelton, "21st Century Satellites," p. 31.

CHAPTER V

REGULATORY AND MARKET SOLUTIONS

Now that the efficiency side of the debate has been presented, it is also equally important to know and understand the equity point of view. This being that regulatory and market solutions to GSO use may or may not increase orbital efficiency but they will at least result in a more equitable allocation of its resources. From the early days of radio, when rival stations would attempt to gain an advantage, on their competitors, by raising their output power, it has appeared reasonable that some regulation was both wanted and needed. This lesson has passed over to satellite planning where it has been practice, since almost the start, for new systems to be implemented only if they will not harmfully interfere with existing ones. If regulation is, thus, necessary, the major issues then become, who should have the authority to regulate and then to what extent? Most would agree that it is the role of the UN and its appointed agents, specifically the ITU, to preside over most international satellite communications

regulation. This leaves extent as the major regulatory issue left to be resolved.

Extent of regulation has been the main topic of discussion at several Space WARCs plus many other regional conferences (RARCs), technical seminars, and planning sessions. Still there is and probably will never be a consensus answer to this question. Issues related to alternative methods to regulate and their relative effectiveness plus who supports each and who doe t, will be the focus of the first half of this chapter. The second half will address the satellite resources as economic assets. If this is the status, who should profit from their utilization: only those actively using the resources; all ITU member nations; or society as a whole?

Regulatory Solutions

The current theme in the subject of GSO use concerns the capacity of the orbit, in the sense of what is practical and cost-effectively achievable at any point in time. This question is critical from a regulatory standpoint because if orbital capacity is seen to be insufficient to meet projected demand (it being assumed that capacity and demand are estimated for the same period of time), then it becomes evident

that regulatory agencies must take an active role and somehow distribute parcels of the resources to those wishing to make use of it. On the other-hand, if the capacity estimates significantly exceeds requirement forecasts, regulation can then be much more passive, allowing matters to evolve as they will, perhaps only instituting certain minimum technical standards which prevent gross waste of the resources.[1]

As far as regulation is concerned, there are three areas that will be discussed here of which none are mutually exclusive of any of the other two. The first to be covered is government regulation, which deals with the way national governments possess the ability to effect change in the world communications community. Next, is the current system of regulation of communications via international bodies. Since this subject was thoroughly covered in Chapter III, the primary focus of this section will be ways to make the present system work better. Last, will be the allocation of orbital resources based on unique need or value. Unique need is when certain services, which can only be provided through satellites, are given priority over others which can be met via alternative methods. Prioritization based on value

is when satellites which provide the highest social benefit are considered for resources first.

Government Regulation

Government policy has a significant influence on domestic satellite communication industry and can, with countries like the U.S., even impact the world telecommunications infrastructure and policy. This does not occur in an orderly and predictable manner because the governments and approaches to regulation differ greatly from nation to nation. Consequently, satellite communications industries have developed at different rates and in different patterns around the world. Arguably however, the factor most affecting satellite regulation is the ever advancing nature of satellite technology. As it moves ahead, it provides challenges to the regulatory systems themselves. For a regulatory system to have impact, it must not only be flexible enough to conform to technological growth but must also be rigid enough to drive progress when the situation so dictates.

The United States is the best place to start when it comes to addressing the pluses and minuses of various regulatory approaches. In the early years of the space age, U.S. satellite industry was strictly regulated. Being an INTELSAT signatory, competition

in the satellite communications arena, against COMSAT and INTELSAT, was prohibited. Most private satellite effort at that time was in support of the Department of Defense and NASA. The U.S. however, had a purpose and because of it, they were very successful. In the commercial communication industry, it was the purpose and burden of COMSAT to design, develop, produce, and operate a global satellite communications system. It was NASA's and I might add the American people's goal and ambition to land a man on the Moon and return him safely. The U.S. accomplished all of these goals and then some but as the objectives began to disappear so too did the American lead in satellite technology.

The early 1970s were a down time for the U.S. domestic satellite industry but all of that turned around with the founding of the "open skies era." Profit was now the motivating driver of the U.S. aerospace industry. Again those industries surged to the forefront in space research, application, and technology but this time in a much less regulated system. This might seem to indicate that a country's success or failure in space technology is independent of their space regulatory policy. To the contrary, the early success of the U.S., under a more tightly regulated structure, seemed to be caused by this

country's goal of beating the Soviet Union in the space race. Once that mission was accomplished, it was only a matter of time before the rest of the world started to catch up to, and in certain cases pass, the U.S. in space technology.

The last fifteen years seems to indicate that a loosely controlled satellite industry is best when the purpose is to encourage technological innovation. For example, in Europe where resources are plentiful but regulation by the PTTs is fairly controlled, the number of prominent space operations are limited. If not for Arianespace and the multinational ESA, Europe would have no significant success stories. The USSR is an example of a country that tightly controls its aerospace industry and thus, has had few technology breakthroughs since its shocking launch of SPUTNIK in 1957. Although they launch a lot of payloads every year, this may be due more to the more expendable nature of their spacecraft than to any advances in space operations.

So, if tightly controlling domestic satellite industries is not the preferred way for regulators to influence the future of GSO communications, then what is? Since the GSO orbit and the satellite frequency bands are international resources, it is implausible

to think that individual nations could sit down one-on-one to decide how these valuable resources should be used. To some degree such meetings could be used to increase adjacent system coordination but use on a larger scale would most likely lead to a very chaotic situation. The desirable setting for global resource allocation is a regional or international forum where the views of all concerned parties can be voiced. In this type of setting there is a definite role for the national regulator but with the polarization of world opinion on GSO use this role has diminished. The one nation one vote procedures used by the ITU no longer allows industrialized nations to dominate world radio conferences. The more numerous developing countries, however, are often willing to compromise with the developed nations because to not do so could result in nonacceptance by countries like the U.S., and a nearly worthless regulation would be on the books. In this minor way regulators from the large developed countries are in effect given preferential treatment and thus, possess the ability to greater influence GSO use.

The most important responsibility of national governments in space communications is the regulation of technical change when it is needed. Specifically,

they can mandate that satellites have to meet certain requirements to operate in specific zones, to provide certain services, or to operate at all. Usually this is over and above what is stated by international law and is required because of extraordinary national or regional needs. In the U.S. the role of determining such needs falls to the FCC. The process however, is no different than the FAA setting airplane standards, the Environmental Protection Agency levying emission standards for automobiles, or the Coast Guard setting safety standards for boats. One thing in common with all these standards is that, as society dictates and technology allows, they become more rigid over time.

An example of such standards toughening has been the FCC mandated reduction in American satellite spacing. Originally set at 5^{o}, satellite spacing has subsequently been reduced to 3^{o} and presently to 2^{o}. This current FCC mandate is at least 1^{o} stricter than international regulation and is needed because of the high U.S. requirement for satellite telecommunication services. Such directives are typically difficult to implement but are nonetheless necessary. Spacecraft spacing reductions required the retrofitting of earth antennas, more directive antennas, and the relocation of satellites in orbit, to name but a few of the

required adjustments. However, as is common with such government mandates, it not only increased the communications capacity of the GSO but it also advanced the state-of-the-art in several satellite technology areas.

Regulation Through International Bodies

The major telecommunicating nations, such as the United States, most of Western Europe, Japan, and the U.S.S.R, want to be able to use the geostationary orbit as they need to. The have-nots, the nations of little or no present satellite needs, are afraid that all the positions will be filled by the time they are ready to use them, and so want orbital locations pre-allocated for each country. The developed countries reply that advances in technology will permit greater communication capacity from each slot, and will allow satellites to be spaced closer together, so that when a country wants a slot, one will be available. They also argue that pre-allocation wastes precious space now, and is thus inefficient.[2] So rages the battle! The duty of the international regulatory community is to resolve this equity versus efficiency dispute. In general, however, people are afraid of being left out either now or in the future, and thus are very averse to compromising their principles and values.

Basically, the selfish national interests, of nations on both sides of this argument, have gotten in the way and historically slowed the international regulatory process to a crawl. In reality, there are difficulties with respect to both sides of this dispute. The two sides of this battle, as presented by their most ardent supporters, reveals some flaws in logic. Donald C. Tice, the Deputy Director, of the U.S. Delegation to the 1985 Space WARC had the following to say on behalf of the developed nations perspective:

> "[The consensus in the United States is that it is essential] to provide an acceptable guarantee of access to the GSO for all countries, while retaining the flexibility which will allow the continued introduction of new, more efficient, and more economic technology."[3]

The major flaw in this proposal is that technology advances are often very expensive and when advances do occur they may not be fast enough to keep pace with the rapid growth in communications demand. With advanced technology being so expensive, it makes very little sense for the developed nations, who are most able to afford these added expenses, to exhaust the use of existing lower cost space resources and then leave the poorer less developed nations burdened with the cost of launching satellites using more advanced technologies. The lower cost orbits and

frequencies should be considered first for use by less developed countries (often called the new-comers premium). This will allow their earliest possible entry into the space communications arena, at the least possible cost. The developed countries, which are not only richer but are also the ones making the technological advances, should be required to first look to the newer high cost space resources to meet their needs. In other words, poorer countries would have first priority on established space resources, while richer countries would be motivated to advance satellite technology as fast as demand dictates. The idea represents a compromise that is equitable to the undeveloped countries and at the same time encourages technological advancement at the expense and stimulus of the developed nations.

Technology will no doubt increase the orbit capacity of the GSO, but will this increase keep pace with the demand for resources. Canada's R.G. Amero, who chaired the technical committee at the 1985 Orbit Conference does not think so. He stated his opinion like this. "Improvements in technology will not make up for the immense increase in satellites that will be launched in the next decade."[4] A primary reason for this is that advancing technology may expand the

GSO slower than it makes developing countries able to launch satellites. An example of such an advance may be VSATs. Their ease of installation may prove more useful to the Third World than to developed nations. Rather than an alternative form of communications in the Third World, VSATs offer a rapid and economical means to introduce communications where none existed before.[5] As the space capabilities of the developing nations increases so must the ability to regulate it. This indicates that a more rigid regulatory model is required than has been proposed by developed nations, to deal with increased satellite resource demand that can not be accommodated by enhanced orbital capacity.

An advocate of the developing world position is Cheikh Tidiane Ndiongue, Communications Directeur for the Republic of Senegal. Asked his opinion on technology providing the necessary future slots for the developing world, he had the following response,

> "That has always been the reflection of the U.S. delegation. Requirements for use of the GSO will increase faster than the evolution of technology. All positions are not good for all countries. There are privileged positions. Interest of the big users and not the interest of the developing countries. It is a limited natural resource for use by all humanity. It is necessary to plan to be fair to all to use fairly."[6]

Another advocate of the developing world position is T.V. Srirangan, who was Secretary of the Indian

Ministry of Communications at the time of the WARC Conferences and has now joined the staff of the ITU. He had this to say,

> "One cannot but take note of arguments which continue to be advanced that the future needs of the developing world can be met by technology advances. This shows inadequate awareness of the technology situation in the developing world and of their aspirations for achieving a substantial measure of self-reliance in technology, either individually or collectively. Developing nations attach great value to this, for they have learned their lesson from their own history and do not wish to be subjugated by yet another kind of dependence. There are also overtones of national pride and prestige, and this is true of all countries. The technology advance premise does not respond to these concerns."[7]

Few would argue that the primary goal of any regulatory process should be the equitable treatment of all affected parties. This can result in being fair to none. Being fair is no doubt the desire of the ITU in its Space WARCs. Unfortunately, the international regulatory process has evolved into a slow and overly arduous process with emerging plans taking too long to make, causing many to be obsolete by the time they are implemented. Some means must be devised to continue to advance the developing world's goals and at the same time maintain the technological expansion of the GSO. Rigid international regulation as advocated by developing nations is not the answer.

Implementation of the ideas discussed earlier is a start, but this does not address the current out modded regulatory process. One answer to this may be to move away from the world regulatory scheme towards a regional regulatory scheme. A regional scheme will allow the particular communicating needs of countries to be addressed only by other nations that are themselves familiar with and sympathetic to the regional situation. After all, argue the advocates of this approach, why should European nations have any input concerning North and South American space regulation and vice-versa. The success of this type of plan can be seen by reviewing the 1983 Region II conference on direct broadcasting satellites. It devised a program that was more flexible and better met the demands of the regional nations, than did the international DBS plan. In addition to better meeting national needs, such a plan would be more timely in nature and have the ability to change rapidly to meet changing times.

Prioritization Based on Unique Need or Value

Allocation of space resources based on unique need or value would most likely be implement as part of an overall international, regional, or national regulatory scheme. The major difference between a plan of this type and any other regulatory plan is

the criterion used for allocation of orbital slots and frequencies. Nations and or organizations would still need to list their needs, which would then probably be fed into a computer to determine resource allocation. Instead of every organization and nation getting an automatic allocation as their piece of the pie, prioritization now would be based on unique need or value. Additional explanation of unique need and value is needed to understand this proposal.

Prioritization based on unique need would be a process where-by services which could only be met via communications satellite would be given priority when allocating orbital slots and frequency spectrum. Those best served by satellites would be considered next, while those served easiest by other means would receive lowest ranking. For example, one might argue that satellites utilized for mobile and DBS purposes should have priority over a fixed satellite used for transcontinental telephone service, and thus, could easily be replaced by fiber optic cables. This type of process would ensure the most optimum utilization of satellite resources but would also place an unfair handicap on those services deemed to be less in need of satellite communications.

The allocation of satellite resources based on value is a priority scheme that gives preferential treatment to space services deemed to be in the best interest of society. Services that could fall into this category include meteorological, mobile, search and rescue, and defense plus multipurpose satellites. The major problem with such a prioritization approach would be how to determine the criterion for societal value. After-all, determining what is in society's best interest is hard enough on a national level let alone trying to extend it to an international forum.

One group that would surely benefit from this type of arrangement are the Common User Organizations (CUO) such as INTELSAT. Though they are collectively the largest single element in international satellite communications, they have been almost totally locked out of all discussions related to the allocation of space resources. They are the guarantors of global access for most ITU members (about 120 of the unions members belong to one or more CUO, the remainder are, by and large, mini-states with little international traffic).[8] With such backing it is likely that CUOs would receive high priority if space communications resources were allocated based on international social value.

Market Solutions

The allocation of satellite communication resources via a market driven system is extremely fascinating. A major question is how should such a system be set up? Should space be considered an asset of society, with control sold or leased by an international body such as the United Nations or should it be considered a resource to be allocated to the nations of the world, as are other natural resources such as water and mineral rights. In either case, who should benefit from the profits of such a market system? Individual nations, users, the global community, or some other group! Finally, how are systems that are already in place or planned for near term launch handled?

Total Open-Market Approach

A total open-market approach for allocation of orbital slots and frequencies would be one whereby all resources would initially be the property of some international body like the United Nations. It would be their burden to sell or lease the space resources. If resources are sold, they would become the property of the purchasing group or nation. At the purchasers discretion, the resource could be leased, resold, or

used. If the assets were leased, either by the UN or a second party, they would be available for use by that party for a specified period of time, at which time the lease could be renewed, if mutually agreed upon, or the asset would be returned to the leaser. On the surface, such a system appears to have merit but before reaching any final conclusions, it may be wise to review its pros and cons.

Backers of a market oriented space resource allocation system would argue that it will increase both the efficiency and equity of GSO use. Equity would be enhanced because profits from the sale or lease of orbital slots and frequencies could be used to further the telecommunications capabilities of the less developed areas of the world. The present plan only yields windfall profits to a few organizations and countries that have the technical and financial ability to launch satellites into orbit and operate them their. In a totally market oriented approach, some of those windfall profits would be recaptured for society. Equitable access to the GSO and other space resources would, thus, be enhanced by speeding the entry of the less developed world into the space communications arena.

Supporter's increased efficiency argument is that the present system for allocating communications resources makes inefficient use of them, resulting in their scarcity. A market system leads to equilibrium by not only reducing the demand for but also increasing the supply of usable bandwidth and orbital slots. Demand will be reduced because the initial high need for satellite resources will drive up the price. As the price increases, the number of potential buyers that are able to pay the higher price will decrease. Eventually, an equilibrium will be reached at a level equal to supply but less than initial demand. Seeing that supply is less than initial demand, the market will force the availability of additional resources by either technical or regulatory means. This will drive down resource prices to a new equilibrium point of supply and demand. As presented, this appears to be a static process but in reality it is really very dynamic, with supply, demand, and prices in constant motion. The only way this process stops is if supply exceeds demand, which in this case is very unlikely.

Markets not only enhance resource utilization but they also remove the hand of international bodies and government as distributors of privilege. In this regard too, price is better than regulatory selection

when it comes to reducing the assignments of spectrum and orbital slots to what is available, thus removing political factors from the weeding out process.[9] No longer would nations or groups be able to claim that they were denied GSO access because of their social, political, ethnic, or religious persuasion.

Unfortunately, there are also many drawbacks associated with the market distribution of resources. The first major concern is that such a system would become very chaotic if allowed to evolve unregulated. Checks and balances must remain in the system so that the evolution of the GSO remains orderly. Examples of such checks might be as follows: 1. An approval system similar to that which currently exists would be necessary to ensure that new satellite systems do not adversely effect existing satellite systems. 2. A committee would be needed to review access to the GSO. Only nations or organizations that abide by the Outer Space Treaty should be permitted to communicate from and occupy the GSO. 3. An organization similar the U.S. Commodities and Exchange Commission would be required to monitor all resource transactions. This would ensure that all resource transfers were being carried out by parties who were authcrized to do so.

The status of current users would also need to be considered in any market plan. The fair means of dealing with this problem would be to grandfather current users into the new market system. In other words, they would not have to pay for their current resource usage but their orbital slot and frequency bands would revert to ITU control upon completion of their mission. This would not give anyone an unfair advantage (e.g. free resources) but at the same time would protect the rights of those that established a space communications business under prior agreement. The most pleasant resulting problem would be how to distribute the windfall. I will not even attempt to answer this question but one thing is for sure, the political factors once involved in the distribution of resources would most likely possess considerable weight in an endeavor such as this.

Regulated Market Approach

A regulated market approach is a plan whereby satellite resources are allocated to nations via some prearranged plan and then the nations have the option to either use, sell, or lease them. It is different from the total open-market approach in two important ways. First, windfalls in a regulated market are not filtered through an international body such as the UN

but are paid directly to the countries in need of the financial assistance. This allows nations to be more self-sufficient and in control of their advance into the space communications era. Second, the UN is not involved in the financial aspects of market transfers of resources but they do have the more important role of determining and maintaining the plan for resource distribution. Such a market approach could easily be instituted under the current regulatory system, with little change in current policy. The highlights of a regulated market system, plus an attempt which tested its viability will be presented in the remainder of this section.

The developing world should be major backers of a regulated market approach because of the large potential benefits which such a system could make available to them. Most space resources received by developed countries are used, while many allotted to developing nations sit dormant. The perspective of the developing world is that through the political control of orbital slots and frequencies, they have a resource that could be used to assist them in their economic development.[10] Third-World delegates at the 1985 Space WARC stated a desire to lease their slots (profits to advance their communications situation)

to more advanced users, until they were ready to take over themselves. They equated it to being much like access to the 200 mile ocean zones ceded to them by the Law of the Seas.[11] In the case of ceded ocean zones, countries have the option to lease them to other countries for purposes of oil exploration and fishing. Why then shouldn't they also have that same recourse with their assigned orbital positions and frequencies?

Their are many advantages to a market system for distribution of space resources, not just for the developing world but also for developed nations as well. The obvious advantage to the developing world is the windfall profits, related to selling and/or leasing of satellite resources, which could possibly be made available for their economic development. This would hasten their entry into the communications arena and result in a more equitable distribution of world resources. The advantage to the more developed nations is one of efficiency. GSO efficiency will be increased, because instead of the developing nation's allotted resources remaining inactive for a number of years, they will be available for use immediately. Thus, the number of orbital slots available for use by developed nations will be significantly increased.

With every good idea, there are problems that must be worked out before smooth operation can start. One problem, in this case, is how should resources be distributed? The more resources a nation can acquire free of charge for resale the richer it becomes. For this reason, a plan similar to the one currently used for distribution of resources must be maintained. In other words, advocates of a regulated market approach would say that nations should be allocated their one or two orbital positions in each frequency band to do with as they wish. Any additional resources would have to be petitioned for, showing a legitimate need. These additional positions could be either borrowed, leased, or purchased from the ITU. If borrowed or leased, these resources would be returned to the ITU upon completion of the assigned satellite's mission. If the ITU sells unassigned satellite resources, they become the asset of the purchaser to use as they see fit. As with the open market approach, checks and balances are needed to ensure the proper operation of the system. These would need to include at least the technical, financial, and regulatory, controls listed in the previous section.

Two other problem that must be addressed are regional systems and the status of nations that sell

their allocated resources. Under current allocation plans, nations that participate in regional satellite systems lose their assigned orbital positions for the time that they belong to that regional system. They, thus forfeit the right to sell or lease that resource if they so chose. This policy seems to be unfair to nations that can least afford to lose such potential revenue. Critics of this policy believe that only one of the countries involved in a regional system should be required to give up their assigned orbit position for each satellite used by such a system. This would likely mean that all other members should pay rent to those that forfeit their slots. Members not forfeiting their slots would then presumably be able to sell or lease their own resources. Another question remains, should shortsighted nations, that sell their allocated resources, be forever barred from participation in space communication or should they be allocated additional resources. Countries which sell their slots probably should not be given additional assignments, but should have the option to petition for or purchase a new slot if their need so dictates. In this way, they have the ability to reenter the satellite communication arena. If no additional slots are available then that country

would have no options other than to try to join a regional system, rent transponders from an under utilized satellite operator, or wait until added resources are made available.

One of the first nations to attempt to profit from the sale of their assigned orbital resources was the South Pacific island of Tonga. Under the outline proposed by the American consultant Matt Nilson, the island of Tonga filed an application, with the IFRB, to launch and operate a satellite. Their spacecraft, TONGASAT, was in reality a paper satellite with very generic specifications. They did not intend to place TONGASAT in orbit but only wanted authorization and clearance to launch a satellite into that location. The plan from the outset was to find someone with a real satellite, which matched closely with their proposal and in essence sell their orbital slot to that user. Their orbital assignment was accepted by the ITU and so the only thing left to do was to find a buyer for their product. At one point, a likely candidate was ASIASAT.[12] Initially an orbital slot for ASIASAT was promised by the Chinese government but the offer was withdrawn. At this stage their only other recourse was to buy the slot from Tonga. ASIASAT, however, eventually concluded an agreement

with China and so Tonga was without a purchaser for its slot. This process was started around 1986 and to date all attempts to market and sell their resources have been unsuccessful.[13] If someday they are successful, they will be in the history books as the starters of a new era in international satellite communications with the sale of real estate in the Clarke orbit.

NOTES-CHAPTER V

[1] Donald M. Jansky, and Michel C. Jeruchim, Communication Satellites in the Geostationary Orbit, (Norwood, MA.: Artech House, Inc., 1987), p. 256.

[2] Mark Chartrand, "WARCing Together." Space World, October 1985, p. 12.

[3] Donald C. Tice, "Issues in U.S. International Telecommunications Policy," In New Directions in Satellite Communications, Challenges for North and South, Ed. Heather E. Hudson, (Dedham, MA.: Artech House, Inc., 1985), p. 287.

[4] Debora MacKenzie, "The Poor and Rich Jostle for Space," New Scientist, 29 August 1985, p. 17.

[5] Edwin B. Parker, "Future Perspectives on Satellite Communications," Telecommunications, August 1987, p. 47.

[6] Cheikh Tidiane Ndiongue, Directeur de la Communication for the Republic of Senegal, Personal Interview, 29 August 1989. Interview was through an interpreter and quotation may not reflect the exact words of Mr. Ndiongue.

[7] T.V. Srirangan, "Why Orbit Planning: A View from a Third World Country, Part II - Issues for WARC (ORB) 85 & 88: Some Perceptions," In New Directions in Satellite Communications, Challenges for North and South, Ed. Heather E. Hudson, (Dedham, MA.: Artech House, Inc., 1985), pp. 275-276.

[8] Wilson Dizard, "The Role of International Satellite Networks," In Tracing New Orbits, Cooperation and Competition in Global Satellite Development, Ed. Donna A. Demac. (New York: Columbia University Press, 1986), pp. 229-230.

[9] Ithiel de Sola Pool, Technologies of Freedom, (Cambridge, MA.: The Belknap Press of Harvard University Press, 1983), pp. 139 & 148.

[10] Jay C. Lowndes, "U.S. Strategy Aims at Loose Regulation for Orbit, Frequency," Aviation Week & Space Technology, 25 November 1985, p. 87.

[11] MacKenzie, p. 17.

[12] ASIASAT is a regional system that is based upon a refurbished WESTAR satellite recovered from space. It is a joint venture of Cable & Wireless, Ltd., Hutchenson, Ltd., and the Chinese government.

[13] Joseph N. Pelton, Director of the Interdisciplinary Telecommunications Program, Colorado University at Boulder Colorado, Personal Interview, 17 April 1990.

CHAPTER VI

CONCLUSIONS

If there is one primary idea that should be drawn from this thesis, it is that absolutes do not exist, concerning the issue of geostationary orbital crowding. Technology by itself will not ensure the equitable and efficient use of the GSO. The setting aside "valuable resources" for nations that may never use them is not the answer. Unfortunately, the world is polarized on this issue, with the developing and developed countries both pursuing self serving goals, which are not to the benefit of the global community, as a whole. There is some middle ground however, and that is precisely what this last chapter will attempt to show. The first part of this chapter will address the high points of the four main chapters, to review the issues that should be kept in mind when devising policy concerning satellite communications. Last to be presented is a recommendation of a compromise that may provide for equitable and efficient utilization of the geostationary satellite orbit.

First before proceeding with this conclusion, these words from former Ambassador Diana Lady Dougan very concisely expresses what the role and philosophy of the international satellite community should be if it expects to continue the successes of the past.

> "If satellite professionals are to celebrate the next fifteen years in space with the same pride as today, they must continue to commit themselves to three concepts: Innovation to take the fullest advantage of technological opportunities; Adaptability to meet changing user requirements; and Motivation to persuade policy makers domestically and internationally, to accept change.[1]

Such a philosophy, if followed, would be a good start in the right direction towards assuring an efficient and equitable use of the GSO and its resources.

Review of Problems and Solutions

Communications by way of satellites is now part of the lifestyle in most developed areas of the world. They serve many "basic" needs like providing television, telephone, and emergency services to name but a few. In most cases, satellites are so entirely integrated into the total domestic and international telecommunications systems, that they are virtually transparent to end users. There are many advantages, to satellite communications, that make it superior to other transmission mediums for providing many crucial communications services. These include, but are not

limited to, a satellites "relative" insensitivity to man-made and naturally occurring obstacles, distance, and remoteness. Satellites would also, most likely, be the preferred form of telecommunications service for the developing world (especially for rural areas) if they were technically and financially capable of affording them. Unfortunately, most are not and thus the gap between the developed and developing world's communications capabilities continues to grow.

There are many different types of satellites used for various functions, with each having its own unique needs and requirements. This makes regulating space assets that much more difficult. Some diverse types of spacecraft include those used for broadcast, fixed, mobile, military, search and rescue, satellite relay, and scientific services. In common, with most of these satellites, are certain similar elements, to include the communication, station keeping, and power generating and conditioning subsystems. These three elements were addressed in some detail in Chapter II, however, these two main points are most important to remember. First, advances in communication and power generating and conditioning systems will be needed to ensure that the best possible use of satellite orbits and frequencies is achieved. Second, station keeping

technology is not now and most likely will never be a limiting factor on the communications capacity of the GSO or any other satellite orbit.

There are various domestic and international organizations which participate in the regulation of satellite communications service. Every country and regulatory body has its own political, economic, and social agendas, that they try to persuade the rest of the world to consider favorably. Most influential of these bodies is the International Telecommunications Union, which provides a forum for the world to voice their communications demands. Important is the fact that it utilizes a one-nation-one-vote procedure when deciding on communications policy, thus, allowing the less developed nations to significantly influence the direction of world communications. Arguably, their greatest influence has been in the area of satellite communications where they continue to demand fair and equitable access. Herein lies half of the equity vs. efficiency debate among the developed and developing nations. Though the ITU has been semi-successful in establishing current global satellite regulations and procedures, the road has been very slow and is lined with many questionable outcomes.

There are many methods available now and in the near future for increasing the efficiency of the GSO and other satellite orbits. Those available now include: 1. Increasing spacecraft capabilities and use, and thus expanding the communications capacity of the GSO. 2. The use of nongeostationary orbits, which results in more satellites being available to serve communications needs. 3. To utilize advanced coordination techniques that increase the efficiency of satellite communications operations. 4. Enhanced communications techniques and antenna designs have a two-fold effect of increasing both the capability and number of satellites that can occupy the GSO. 5. Use of higher and more frequencies allows more satellites to communicate from the geostationary orbit without creating harmful interference.

Additionally, continued progress to enhance the state-of-the-art in currently viable technology, plus incorporation of future alternatives as they are made feasible should ensure the availability of added orbit-frequency resources well into the next century. Future advances include the utilization of satellite clusters, space platforms or multipurpose satellites, low earth orbit geostationary satellites with 24-hour periods, and intersatellite links. Separately, these

means just discussed will substantially increase the number of satellites that can harmoniously operate in the geostationary orbit. Together, they provide the prospect of a very massive increase in frequency and orbit capacity, quite possibly enough to meet future near term potential needs. However, on the down side they also often impose penalties on earth station and satellite owners. Table 6.1 lists possible satellite utilization enhancements and estimated corresponding improvement factors for each.

Developing nations, however, at times seem to reflect an unwarranted fear of high technology. What is somewhat bewildering about this is that it appears on the surface at least that developing nations would want to encourage spacecraft advancements that result in better use of the orbit-spectrum resources. Such technological advances, should benefit the developing nations by providing for them a more cost effective means to realize their communications goals.[2] The threat, though, that there may not be spacecraft resources available for them when they are prepared to launch satellites is a far greater hazard than any benefits which may arise from technological advances.

The most important responsibility of domestic regulators may not be to regulate use but to push for

Table 6.1. Potential Utilization Improvement Factors for Communication Satellites in the GSO

Purpose	*Technology*	*Change*	*Approximate Improvement Factor*	*Notes*
Reducing Intersatellite Spacing	Antenna Beamwidth Reduction	Larger Antennas 30m vs. 11m	2	Increased Earth Station Cost
	Antenna Sidelobe Reduction	7.5 dB Reduction from CCIR Standard	2	New Antenna Technology
	Station-Keeping	±1° to ±0.1°	1.8	Recent Satellites Have ± 0.1° Capability
	Optimum Positioning	Multilateral Coordination vs. Bilateral Coordination	1.5	Complex Coordination and Increased Satellite Cost
	Modified Orbits	Inclined and Eccentric Orbits	2–4	New Station-Keeping Technology
Increasing Effective Bandwidth	Available Frequencies	Bandwidth Increase from 1000 MHz to 5500 MHz	5.5	New Communications Technology
	Beam Separation	Global Coverage to 6 Spot Beams	6	Limited by Concentration of Traffic
	Polarization	Unpolarized to Dual Polarization	2	Implemented on Some Recent Satellites
	Uplink-Downlink Assignments	Alteration of Uplink-Downlink Frequencies	1.8	Interference and Coordination Problems
	Intersatellite Links	Elimination of Double-Hops	1.1	New Satellite Technology
Increasing Communication Efficiency	Modulation and Multiple Access	FM/FDMA to DSI/TDMA	3	Increased System Cost
	Data Compression	Voice and TV Signal Compression	3–6	New Communications Technology

Source: Rita Lauria White and Harold M. White Jr, The Law and Regulation of International Space Communications, (Boston: Artech House, Inc., 1988), p. 25.

technical change as the FCC did by mandating maximum U.S. satellite spacing at 2°. There is little doubt, however, that some regulation of service is needed to ensure the proper and equitable utilization of shared international space resources. A currently existing regulatory mode that may prove more effe:tive in the

future for ensuring equitable access to the GSO might be regional conferences. They have historically been more successful because they tend to involve meetings between more homogeneous players. Another alternate regulatory method, which should be considered, is to allocate resources based on unique need and/or social good. This type of practice would prove most useful should the demand for geostationary resources become so great that no alternative solution could possibly achieve the desired results.

Some experts insist that both efficiency and equity of GSO operations can be improved by marketing orbit-spectrum resources. Efficiency would be aided because of the inherent nature of supply and demand economics while equity would be improved because any windfall from such a system would be realized by all society and not just by satellite users. Questions still must be resolved concerning how to run such a system, who should be the primary benefactors, and how to regulate and control market operations?

Recommendations

No thesis on this subject would be complete without at least attempting to establish a possible solution to this growing international equity versus

efficiency dilemma. To this end, no-one will be let down or disappointed.

Any viable solution to geostationary orbital crowding must start by first implementing all genuine technical solutions/advances. This will not be very popular with developed nations because it would cost them both time and money. The industrialized nations would much rather exhaust existing satellite orbital resources and then concern themselves with creating added capacity as technology permits. A system such as this would neither advance the goal of GSO equity nor efficiency.

Some unpopular but necessary guidelines for obtaining the greatest possible utilization from the space resources include the following: 1. Developed operators should be encouraged to implement advanced technologies and use the higher frequencies. The "C" band assignments if at all possible must be saved for the developing countries. This will force developed countries to bear the burden of the satellite world's advance into the next century but then again wouldn't they bear this load under any circumstance. 2. Every orbital position should be used to the fullest extent possible. Large capacity and multipurpose satellites must be encouraged where at all possible. Plans must

be made to share excess capacity whenever it exists. 3. Operators that do not need 24-hour service should be required to use orbits alternative to the standard GSO. Nations far north or south of the equator must also seriously consider orbits such as those used by the MOLNIYA spacecraft system. 4. More effort should be placed towards the development of an international satellite coordination scheme which incorporates the methods of reverse bandworking, orbit sectorization, and frequency segregation. 5. Progress must continue to advance the state-of-the-art in all technology and procedural areas of satellite communications.

Now that the orbital efficiency facet of this problem has been addressed, so too must the fairness concerns of the less developed countries. When asked if he thought it to be wasteful to set aside "scarce natural resources" for the less developed world, when those resources could potentially be used by current legitimate operators, Mr. Ndiongue, the Directeur of Communications for the Senegal had this response,

> "Each country, 166 members of the ITU, have 800 MHz of frequency band for fixed satellite service [in both the "C" and "Ku" spectrum bands] and one orbital position [larger nations allocated more] to cover all of their country. This development plan only utilizes 10% of resources. Any other users can use the remainder of the resources on a first come first serve basis. Mostly the bigger users, with about 400 existing systems using the orbit."[3]

While it is agreed that some sort of orbital allocation plan is needed to give developing nations a stake in the international telecommunication arena, allowing valuable resources to remain unused is not the answer. A better approach would be to allocate the standard fixed satellite service orbit positions and associated spectrum to the developing countries but then permit those resources to be used by other nations until the "owning" nation has the ability to use its assigned positions. Implementing this type of plan should not be too difficult considering the long lead times associated with the development and launch of satellite systems. If no satellite is now planned by the assigned owner, then it is reasonable to estimate that the orbital slot will be available for use by another operator for at least 5 and most likely 10 years. More than enough time to get some valuable use from these resources.

One important question is who should benefit from the sale, lease, or allocation of these orbital resources? Based on current international precedent (Law of the Seas and sovereign air space), it should be the assigned nation which should reap the rewards. Such a system, in addition to being equitable, could also potentially provide developing nations with the

needed capital to allow their advance into the latter portions of the space age. If, however, this was not an acceptable solution to the ITU or other interested parties then some other plan could be devised. These might include allocation based on unique need, social value, first-come-first-serve, or even a market plan administered by the ITU. The most important concept here is that satellite orbital slots and frequencies must not be allowed to remain empty.

The near term answers for many developing countries may be in the form of existing or proposed regional or specialized telecommunications satellite systems. They offer an opportunity for both enhanced use of the orbit and guaranteed access. Systems such as EUTELSAT, ARABSAT, PALAPA, and CONDOR are examples of regional satellites which, by serving the needs of multiple countries, can both guarantee them access to the GSO and also relieve demands on orbit resources. Specialized systems such as ORIONSAT and PANAMSAT are examples of systems designed to optimize spectrum use to serve particular user requirements through the use of high power spot beams. The PACSTAR system, though still largely a "filing" rather than an satellite, is an example of both a regional and specialized system. It has been designed to make efficient utilization of

the orbit through high-power spot beam technology and at the same time to provide access to the orbit for a wide spectrum of user economies, that might otherwise not be served.[4]

Technical, regulatory, and financial experts from around the globe have been attempting to resolve the problem of geostationary orbital crowding for the better part of two decades. The fact that they have at best experienced limited success may lead some to suggest that this is an unsolvable problem. While it is true that devising the "perfect" solution is most likely impossible, there is a compromise solution out there, which is acceptable to the international space community. The proposed solution in this thesis, while having some flaws, is an attempt to establish such a compromise solution. After-all if we don't try we will never succeed!

NOTES-CHAPTER VI

[1] Diana Lady Dougan, Communications Satellites: Challenges of the Future, Ed. Cynthia Saboe, (Washington D.C.: United States Department of State, Bureau of Public Affairs, Office of Public Communication, Editorial Division, February 1988), p. 4.

[2] Donald M. Jansky and Michel C. Jeruchim, Communication Satellites in the Geostationary Orbit, (Norwood, MA.: Artech House, Inc., 1987), p. 104.

[3] Cheikh Tidiane Ndiongue, Directeur of Communications for Senegal, Personal Interview, 29 August 1989, Interview was conducted through an interpreter and quote may not represent the exact words of Mr. Ndiongue.

[4] Jansky, p. 104.

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APPENDIX A

DIRECTORY OF ACRONYMS

Acronyms	Definitions
ACE	Apogee at Constant time of day Equatorial orbit
AEROSAT	AEROnautical SATellite
AMES	Aeronautical and Maritime Engineering Satellite
ANIK	A Canadian communications satellite
AOCS	Altitude Orbit Control System
ARABSAT	ARAB SATellite communications organization
ARSC	African Remote Sensing Council
ASIASAT	ASIAn SATellite communications organization
BDT	Telecommunications Development Bureau (French)
BER	Bit Error Rate
BSS	Broadcast Satellite Service
CCIR	International Radio Consultative Committee (French)
CCITT	International Telephone and Telegraph Consultative Committee (French)
CDMA	Code Division (Domain) Multiple Access
CIP	Committee and Information Policy
C/N	Carrier to Noise ratio

Acronyms	Definitions
COMSAT	COMmunications SATellite corporation
COMSEC	COMmunications SECurity
COMSTAR	COMSAT developed COMmunications STAR satellite
CONUS	CONtinental United States
COPUOS	Committee On the Peaceful Use of Outer Space
CUO	Common User Organization
DBS	Direct Broadcast Satellite
DFVLR	West German aerospace research and development body
DAMA	Demand Assignment Multiple Access
DOD	Department Of Defense
DSCS	Defense Satellite Communications System
EARLY BIRD	INTELSAT I
ECHO	Large metalized communications reflector balloons
EEC	European Economic Community
EHF	Extremely High Frequency
EIRP	Effective Isotropically Radiated Power
ERTS	Earth Research Technology Satellite
ESA	European Space Agency
EUTELSAT	EUropean TELecommunications SATellite organization
FAA	Federal Aviation Administration
FCC	Federal Communications Commission
FDMA	Frequency Division (Domain) Multiple Access

Acronyms	Definitions
FET	Field Effect Transistor
FLEETSATCOM	U.S. Navy's FLEET SATellite COMmunications
FSS	Fixed Satellite Service
GALAXY	American communications satellite
GEOSTAR	GEOstationary STAR RDSS satellite
GHz	GigaHertz
GPS	Global Positioning Satellite
GSO	Geostationary Satellite Orbit
GTE	General Telephone and Electric
HBO	Home Box Office
HDTV	High Definition TeleVision
HF	High Frequency
HPA	High Power Amplifier
IF	Intermediate Frequency
IFRB	International Frequency Registration Board
INMARSAT	INternational MARitime SATellite organization
INSAT	Indian National SATellite
INTELSAT	INternational TELecommunications SATellite consortium
INTERSPUTNIK	Russian backed regional communications satellite system
IRAC	Interdepartmental Radio Advisory Committee
ISL	InterSatellite Link
ISRO	Indian Space Research Organization

Acronyms	Definitions
ITU	International Telecommunications Union
LANDSAT	LAND SATellite
LOCSTAR	French LOCation STAR RDSS satellite
LOOPUS	Loops in Orbit OccuPied by Unstationary Satellites
LNA	Low Noise Amplifier
LNB	Low Noise Block converter
MHz	MegaHertz
MILSTAR	MILitary STAR Satellite
MOLNYA	A Russian communications satellite
MORELOS	Mexican communications satellite
MSS	Mobile Satellite Service
NiCd	Nickle Cadmium
NiH^2	Nickle Hydrogen
NASA	National Aeronautics and Space Administration
NASDA	Japanese satellite organization
NOAA	National Oceanic and Atmospheric Administration
NTIA	National Telecommunications and Information Administration
ORB	ORBit conference
ORIONSAT	ORION corporation SATellite
OST	Outer Space Treaty
OTV	Orbital Transport Vehicle
PACSTAR	PACific STAR satellite
PALAPA	Indonesian satellite

Acronyms	Definitions
PFD	Power Flux Density
PN	Pseudorandom Noise
PTT	Post Telephone and Telegraph
RARC	Regional Administrative Radio Conference
RCA	Radio Corporation of America
R&D	Research and Development
RDSS	Radio Determination Satellite Service
RF	Radio Frequency
RMA	Random Multiple Access
RR	Radio Regulations
SATCOM	RCA developed SATellite for COMmunications
SCORE	Signal Communicating by Orbiting Relay Equipment
SCPC	Single Channel Per Carrier
SDI	Strategic Defense Initiative
SDMA	Space Division (Domain) Multiple Access
SDS	Strategic Defense System
SHF	Super High Frequency
SPACENET	GTE SPACE NETwork communications satellite
SPUTNIK	The world's first satellite (Russian)
STATSIONAR	A Russian communications satellite
STET	Sun-synchronous Twelve-hour Equatorial orbit
SYNCOM	NASA sponsored, Hughes built, SYNchronous COMmunications satellite

Acronyms	Definitions
TDMA	Time Division (Domain) Multiple Access
TDRSS	Tracking and Data Relay Satellite System
TELESPAZIO	Italian satellite organization
TELSTAR	Bell system developed TELecommunications STAR satellite
TRT	Tropical Radio and Telecommunications
TT&C	Telemetry, Tracking and Command
TPA	Transistorized Power Amplifier
TWTA	Traveling Wave Tube Amplifier
UHF	Ultra High Frequency
UN	United Nations
UNDP	United Nations Development Programme
UNGA	United Nations General Assembly
UNISPACE	Conference on the peaceful use of outer space
VHF	Very High Frequency
VOLNA	A Russian communications satellite
VSAT	Very small SATellite
WARC	World Administrative Radio Conference
WESTAR	WEst STAR satellite